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BRANCH OF FISHERY BIOLOGY
1957

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LABORATORY EXPERIMENTS ON THE UPTAKE, ACCUMULATION, AND LOSS OF RADIONUCLIDES BY MARINE ORGANISMS

Chapter 8

LABORATORY EXPERIMENTS ON THE UPTAKE, ACCUMULATION, AND LOSS OF RADIONUCLIDES BY MARINE ORGANISMS[1]

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What happens to radioactive materials that are introduced into the oceans may be studied by a marine biologist from at least two points of view. As a physiologist, he will be interested in the uptake, accumulation, and loss of radioelements as a function of the element, and its concentration; in the physical factors of temperature, light, and salinity; and in differences between species of organisms, as well as their age and sex, to mention some of the most important parameters. As an ecologist, he will be interested in these same parameters under a steady-state condition. The physiologist would profit most by exposure of the organism to a single dose of radioactive material, while the ecologist must concern himself with the results of chronic exposure.

Both types of biologists may be interested in tracing the history of an element through the food webs of the various trophic levels. Unfortunately, the experimental data involving the metabolism of radionuclides by marine organisms is extremely meager. In this section some experiments will be described on the uptake, accumulation, and loss of radionuclides by various marine organisms in the three trophic levels. It must be emphasized that the results of these few experiments must be extrapolated with extreme caution in predicting what may happen to radioactive materials introduced into the oceans from nuclear reactor plants, bomb detonations, or from any other sources.

In discussing the uptake of radionuclides by marine organisms, it is sometimes difficult to state exactly what constitutes a single or a chronic exposure. For a unicellular alga, a few hours may represent chronic exposure, while a few weeks may be insufficient for a fish to reach a steady-state condition. No long-term repetitive feeding experiments have been done, so for the purpose of this report, we will discuss the metabolism of the various radionuclides solely on the basis of the trophic level concerned.

The term uptake implies passage through a membrane. Radioactive material may be present in the gut of an organism, but until it enters the organism through a membrane, it can play no role in the metabolism of that organism except by producing radiation effects or by interfering with a chemical reaction occurring within the gut. In some of the experiments to be described, particularly those involving phytoplankton, it was not established whether or not the radioisotope was actually incorporated into the organism, or merely adsorbed to the surface. For simplicity, we will therefore discuss uptake in the sense that the radioisotope is associated with the organ or organism in question.

Isotopes of a given element usually have similar chemical behavior, so that in tracing the path of most elements in biological systems, it can be assumed that a radioactive atom will behave in the same way as a non-radioactive atom of the same species. The only parameters to be considered in the discussion to follow will be the species and age of the organism, the element, the concentration of the element, the temperature, and the duration of exposure or treatment. No work using radioisotopes has been done on the mineral metabolism of marine organisms relative to sex. The data that will be presented were collected either at the Fishery Radiobiological Laboratory of the United States Fish and Wildlife Service (R.L.F.W.S.) or the Hawaii Marine Laboratory, University of Hawaii (HML).

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[1] Work performed at the Fishery Radiobiological Laboratory of the U. S. Fish and Wildlife Service and the Hawaii Marine Laboratory (Drs. H. Boroughs, S. J. Townsley, and R. W. Hiatt).

Contribution No. 95, Hawaii Marine Laboratory.

First trophic level

Experiments performed at the R.L.F.W.S. very clearly show that different species of planktonic algae have remarkably different abilities to concentrate a particular element from the sea water medium. Algae were grown in the presence of radiostrontium obtained from Oak Ridge. The material used contained both Sr^{89} and Sr^{90}; the latter decays to form Y^{90}. By counting the algal samples immediately after they were removed from the culture medium, and again after several weeks, in order to allow the secular equilibrium of the Sr^{90}-Y^{90} pair to be reached, it was possible to determine what percentage of the original radioactivity was due to strontium. Table 1 shows that *Carteria* sp. accumulated strontium 89 and 90 from the isotopic mixture, and that *Gyrodinium* sp. removed almost no strontium 89 or 90, but instead accumulated yttrium 90. It was found that *Nitzschia closterium* under an apparent steady state condition concentrated strontium 17 times over its concentration in sea water (weight of algae/weight of water). The concentration factor for strontium *Carteria* sp. was found to vary with condition of culture but was much greater than for *Nitzschia closterium.*

TABLE 1 THE DIFFERENTIAL UPTAKE OF RADIOACTIVE STRONTIUM AND YTTRIUM BY ALGAE

Species	Percentage activity from strontium	Percentage activity from yttrium
Carteria sp.	100.0	0.0
Thoracomonas sp.	50.4	49.6
Amphora sp.	10.0	90.0
Navicula sp.	8.5	91.5
Chromolina sp.	8.2	91.8
Chlamydomonas sp.	6.5	93.5
Nitzschia closterium	6.0	94.0
Nannochloris atomus	5.7	94.3
Chlorella sp.	5.3	94.7
Porphyridium curentum	4.4	95.6
Gymnodinium splendins	4.1	95.9
Gyrodinium sp.	2.3	97.7

Experiments using $cesium^{137}$ show that while different species concentrate cesium to different degrees (Table 2) none of the nine species tested from three families showed any marked concentration of this element from sea water.

TABLE 2 CONCENTRATION OF CESIUM BY MARINE ALGAE

Algae	Concentration factor [1]
Bacillariaceae	
Nitzschia closterium	1.2
Amphora sp.	1.5
Nitzschia sp.	1.7
Chlorophyceae	
Chlamydomonas sp.	1.3
Carteria sp.	1.3
Chlorella sp.	2.4
Pyramimonas sp.	2.6
Nannochloris atomus	3.1
Rhodophyceae	
Porphyridium curentum	1.3

[1] The concentration factor is reported as the ratio of Cs^{137} in the algae (wet weight) to that in an equivalent weight of sea water at an apparent steady-state condition.

The effect of the concentration of an element on its uptake by *Nitzschia* cells is shown in Figure 1. *Nitzschia* cells were grown in sea water to which had been added labelled zinc at three different concentrations. From the graph

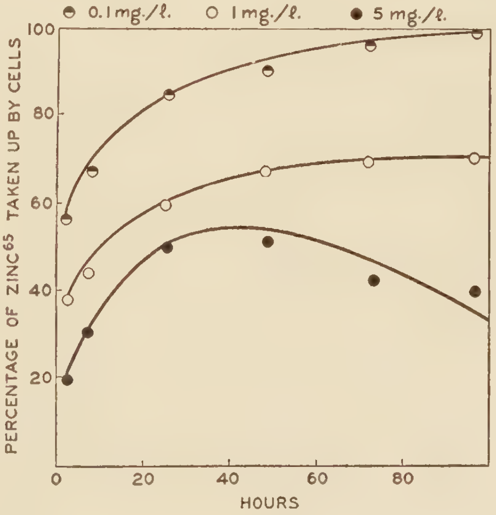

FIGURE 1. Uptake of $Zinc^{65}$ by *Nitzschia* Cells from Culture Medium Containing Different Concentrations of Zinc.

◓ 0.1 mg./l
○ 1 mg./l
● 5 mg./l

it is evident that at low concentrations all the zinc was removed after about four days. The lowest concentration used was still ten times higher than the average zinc concentration of sea water.

The rate of uptake of zinc^{65} by *Nitzschia* cells is shown in Figure 2. At the normal concentration of zinc in sea water, a dividing culture of *Nitzschia* depleted the zinc^{65} in a closed system in less than one day. Apparently phytoplankton cells concentrate zinc relative to sea water and any radioactive zinc present in the water will be quickly taken up in large amounts.

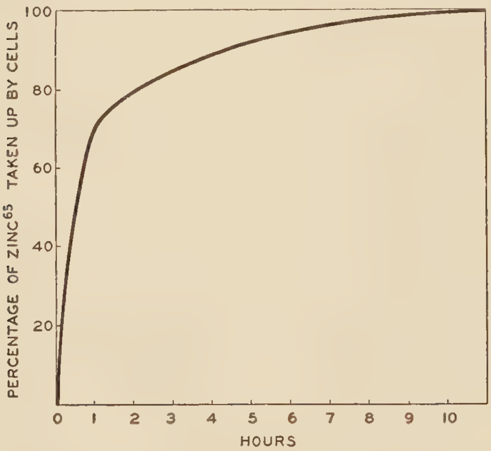

FIGURE 2. Uptake of Zinc^{65} by *Nitzschia* Cells from Culture Medium Containing 10 Micrograms of Zinc/Liter.

The radioisotopes so far discussed are very likely always ionic in sea water. Ruthenium solution, however, forms colloids and particles when put into sea water. Ruthenium^{106} obtained as an acid solution from Oak Ridge was added to a sea water culture of *Nitzschia* cells. Figure 3 shows that the cells continued to take up the ruthenium for the 12 days of the experiment. The amount of ruthenium per cell decreased, however, since the cells of the culture were dividing continually. One may conclude from this experiment, that since the ruthenium concentration in sea water is low, dividing planktonic algae would take up large amounts of any radioactive ruthenium present.

Second trophic level

The work reported in this section was also done at the R.L.F.W.S. Larvae of the brine shrimp *Artemia* were put into filtered sea water containing radiostrontium and the daughter yttrium^{90}. These larvae rapidly took up the SR^{89}-Sr^{90}Y^{90} and reached an apparent steady-state in a few hours. After exposure of the organisms to the isotopes for one day, it was found that the amount of radioactivity/g of *Artemia* was only 70 per cent of that of an equal weight of the sea water. A count of the samples 30 days after their preparation indicated that a considerable amount of Y^{90} was taken up. Other crustaceans used were the shrimp *Penaeus setiferus* and the edible blue crab *Callinectes sapidus*. The molluscan shellfish studied included oysters (*Crassostrea virginica*), clams (*Venus mercenaria*), and scallops (*Pecten irradians*).

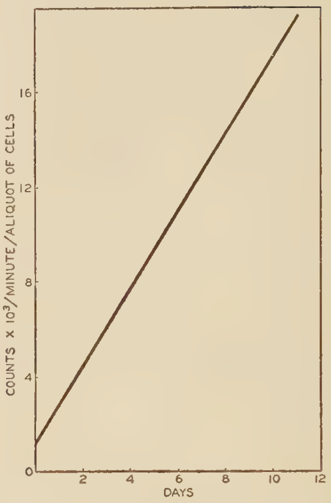

FIGURE 3. Uptake of Ru^{106} by *Nitzschia* Cultures in the Light.

All of these organisms accumulated strontium rapidly from sea water. The internal distribution of strontium in oysters is shown in Table 3. This table indicates that the bulk of the radioactivity accumulates in the shell. When

TABLE 3 DISTRIBUTION OF RADIOACTIVITY IN OYSTERS FOLLOWING EXPOSURE TO SEA WATER CONTAINING SR^{89}

Tissues	Per cent of total weight	Per cent of total activity	Per cent of soft tissues	Per cent of activity of soft tissues
Mantle	2.5	4.1	25.0	27.7
Gills	1.7	3.1	17.5	21.2
Adductor muscle	1.9	2.4	19.2	16.2
Other	3.8	5.1	38.3	34.9
Total soft tissues	9.9	14.7	—	—
Shell	90.1	85.3	—	—

the radioactive shellfish were returned to a normal sea water environment, the radioactivity present in the soft tissues declined within one day to 10 per cent or less of the maximum concentration. This residual amount was held by the tissues for several days.

The uptake of radiostrontium by oysters from food was studied by growing *Carteria* cells in sea water to which Sr^{89} was added. Oysters in Sr^{89} sea water served as the controls; the treated oysters were kept in Sr^{89} sea water to which the labelled *Carteria* cells were added. Fresh sea water and plankton suspensions were prepared each day. The curves in Figure 4 show that an apparent steady-state is reached in eight days. In the unfed oysters the concentration of Sr^{89} in the soft parts is approximately the same as the concentration in the sea water. The oysters which fed on the radioactive algae, however, concentrated the Sr^{89} by a factor slightly greater than two, based on the radioactivity of the suspension per unit of weight. These filter-feeding organisms removed the algal cells from many volumes of water.

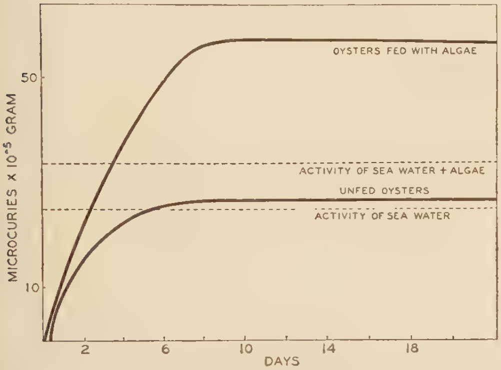

FIGURE 4. The Increased Accumulation of Sr^{89} by Oysters Feeding on Sr^{89}-Fed Algae.

The uptake of $cesium^{137}$ by clams, *Venus mercenaria* L., is shown in Figure 5. At the end of 20 days the soft parts of clams had concentrated the cesium by a factor of six over the cesium concentration of sea water. Obviously a steady state had not occurred, so that it is not possible to say what the final concentration factor of clams might be for cesium in solution. Similar experiments using the bay scallop, *Pecten irradians* L., show that the concentration factor of cesium is greater than eight, since the uptake was still increasing at the end of 10 days.

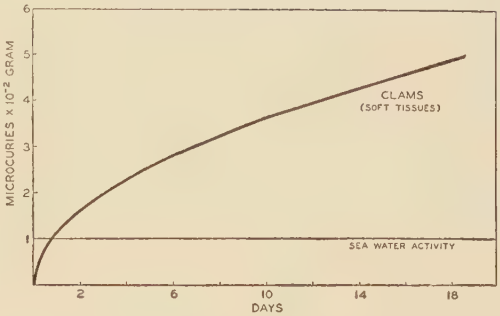

FIGURE 5. The Accumulation of $Cesium^{137}$ by Clams as a Function of Time.

Bay scallops immersed for two hours in sea water containing Zn^{65} very rapidly accumulated this isotope. Table 4 lists the internal distribution of $zinc^{65}$ in the various tissues. The concentration factor for each organ is readily calculated since the activity of the sea water was 10 mμc/g. This means that the figures given in the second column divided by 10 equal the concentration factors. The over-all concentration factor of the soft tissues of the bay scallop was 20 for this short interval. Other observations showed that these scallops contained close to 35,000γ of zinc per gram (wet weight) and thus had a concentration factor for this element of about 3500.

Oysters that were kept in sea water with added Zn^{65} also quickly accumulated the isotope to very high levels. The zinc content of fresh oyster tissue measured almost 170,000γ per gram. This represents a concentration factor of 17,000, since the zinc concentration of the sea water in which the oysters lived was about 10 mcgm/1.

$Ruthenium^{106}$ was one of the separated fission products used to study the uptake of particulate radioisotopes by organisms in the second trophic level. Ruthenium was co-precipitated with calcium carbonate, dried, and ground

TABLE 4 DISTRIBUTION OF ZN^{65} IN THE ORGANS OF THE BAY SCALLOP AFTER A TWO HOUR IMMERSION

Tissue	mμc Zn^{65}/g.	Total mμc
Kidney	1384	824
Liver	243	507
Gills	218	857
Testes and ovaries	138	193
Foot	131	25
Rectum	120	8
Heart	105	13
Adductor muscle	100	375
Mantle	92	321

to a very fine state. Plutei of the sea urchin, *Arbacia punctulata* were put into sea water containing the radioruthenium which was kept in suspension by aerating the culture flask. After 18 hours, the larvae were rinsed and resuspended in fresh sea water. Aliquots of larvae were then removed at intervals and tested for radioactivity (Table 5). A microscopic examination of the larvae at zero time showed that the intestines were filled with the radioactive particulate material, but at 8 hours, very little material was left in the gut. Apparently little ruthenium was actually absorbed through the digestive tract.

TABLE 5 THE DECREASE OF Ru^{106} IN SEA URCHIN LARVAE AS A FUNCTION OF TIME IN NON-RADIOACTIVE WATER

Hours	Radioactivity in 500 larvae (counts/minute)
1	1413
4	179
8	148

The ingestion of the particulate (co-precipitated) ruthenium by the bay scallop, *Pecten irradians,* also indicated that the radioactivity was mostly associated with the digestive tract. The crystalline style was highly radioactive, although the radioactivity in it decreased during the five days the scallops were kept in running water. The hepatopancreas, on the other hand, showed an increase in radioactivity during this time. No radioactivity was found associated with the internal organs other than those in the digestive tract.

Third trophic level

The uptake, accumulation, and loss of radionuclides has been studied in many fishes by both the R.L.F.W.S. and the H.M.L. These fishes include the skipjack tuna (*Euthynnus yaito*), yellowfin tuna (*Neothunnus macropterus*), dolphin (*Coryphaena hippurus*), papio (*Carangoides ajax*), aholehole (*Kuhlia sandvicensis*), *Tilapia mozambique,* menhaden (*Brevoortia tyrannus*), bluefish (*Pomatomus saltatrix*), little tuna (*Euthynnus allitteratus*), croakers (*Micropogon undulatus*), and king whiting (*Menticirrhus* sp.).

At the H.M.L., strontium^{89} in gelatine capsules was fed to skipjack, dolphin, and yellowfin tuna. These are all fast-swimming pelagic fish. Figure 6 shows that the excretion of strontium is very rapid. In 24 hours, only about two per cent of the dose remains in the fish. Similar experiments with *Tilapia,* a small, sluggish bottom feeder, indicate that the strontium is also mainly excreted, but that the time required to reach a minimum level of about five per cent of the dose requires at least four days. This information is consistent with the idea that the metabolic rates of these fishes are very much different, and the sluggish fish might be expected to retain the strontium for longer periods.

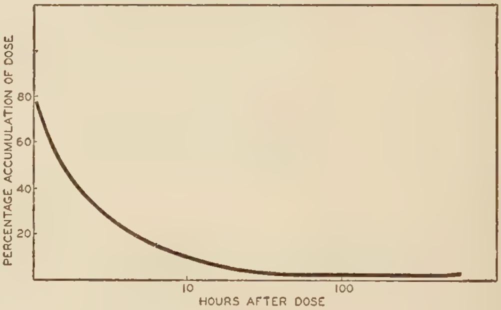

FIGURE 6. The Percentage Accumulation by Tuna Fish of Sr^{89} Given Orally.

The internal distribution of the total radioactivity recovered is shown in Table 6. By plotting the radioactivity of each organ against time, it is apparent that the soft, visceral tissues rapidly excrete the strontium, but that the bony structures, gills, integument, and muscles retain the strontium for a long period. *Tilapia* show the same behavior. The data are presented in Table 7.

The direct uptake of strontium^{89} in solution by *Tilapia* was also studied at the H.M.L. Figure 7 shows that after about two weeks, the

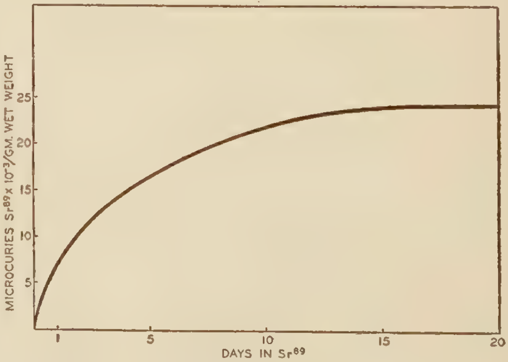

FIGURE 7. The Uptake of Sr^{89} in Solution by *Tilapia Mozambique.*

TABLE 6 ACCUMULATION OF Sr^{89} IN THE VARIOUS ORGANS AND TISSUES OF TUNA AFTER INGESTION

	Percentage of total activity									
	Dose: 5.55μc	Dose: 480μc	Dose: 240μc	Dose: 51.0μc	Dose: 240μc	Dose: 464μc	Dose: 464μc	Dose: 464μc	Dose: 371μc	Dose: 371μc
Tissue	1 hr	2¼ hr	6 hr	7 hr	11½ hr	24 hr	96 hr	264 hr	480 hr	648 hr
Heart	0.04	0.01	0.03	0.049	0.11	0.05	0.028	0.01	0.014	0.007
Gall bladder	0.05	0.04	0.07	0.10	0.08	0.03	0.0001	0.01	0.004	0.002
Blood	4.21	6.68	15.00	0.85	8.07	2.73	1.14	0.35	0.51	0.12
Gill flesh	12.44	0.18	0.91	8.56	5.06	30.61	25.72	2.42	1.42	2.21
Gill bone		1.34	6.47		26.39			16.80	19.48	22.76
Caecum	37.01	7.67	7.84	2.70	2.64	0.34	0.15	0.05	0.04	0.029
Foregut	0.89	9.32	1.12	0.74	1.03	0.20	0.24	0.04	0.04	0.018
Midgut	2.28	14.16	16.50	1.08	1.48	0.65	0.25	0.05	0.036	0.003
Hindgut	11.78	3.98	21.26	2.26	0.11	0.15	0.024	0.03	0.015	0.016
Gut contents	—	48.32	12.73	0.056	19.65	—	0.10	0.013	—	0.0008
Head, operculum	—	0.41	1.09	24.99	6.28	18.33	24.58	28.18	29.91	24.58
Appendicular skel.	3.60	0.40	1.19	36.21	8.45	23.69	30.32	29.15	30.47	31.43
Liver	3.34	1.48	3.04	0.39	2.46	0.15	0.04	0.03	0.04	0.027
Spleen	0.20	0.32	1.39	0.08	0.60	0.03	0.008	0.03	0.010	0.003
Tail	—	0.42	0.15	—	0.00	—	—	—	—	—
Brain, spinal cord	0.23	0.00	0.01	1.24	0.05	1.66	1.70	1.33	0.030	0.004
Eyes		0.04	0.06		0.60			2.02	1.34	1.34
Integument	5.28	1.69	0.86	10.20	5.89	7.69	11.37	13.73	10.25	10.51
Integument flesh (aliquot)	—	0.01	0.01	—	0.05	—	—	—	—	0.065
Integument scales (aliquot)	—	0.02	0.02	—	0.11	—	—	—	—	0.091
Gonad	2.40	0.09	0.47	0.22	0.08	0.06	0.004	0.03	0.023	0.020
Kidney		0.08	0.16		0.09		0.027	0.07	0.035	0.022
Light muscle	16.23	3.23	8.74	4.19	10.01	12.84	3.94	5.26	5.69	5.79
Dark muscle		0.10	0.86	5.25	0.70	0.72	0.48	0.47	0.63	0.95

TABLE 7 THE INTERNAL DISTRIBUTION AND PERCENTAGE RECOVERY OF A DOSE OF 75 μC OF Sr^{89} BY *Tilapia*

Days after dose	Tissue	Percentage of total recovered
1	Skin	25.27
	Eyes	0.35
	Visceral organs	1.82
	Gills	15.62
	Muscle	5.65
	Skeleton	51.30
	Total	100.01
2	Skin	24.44
	Eyes	0.18
	Visceral organs	1.08
	Gills	8.13
	Muscle	3.10
	Skeleton	63.07
	Total	100.00
4	Skin	24.56
	Eyes	0.25
	Visceral organs	1.01
	Gills	6.42
	Muscle	8.40
	Skeleton	59.35
	Total	99.99

TABLE 7—*Continued*

Days after dose	Tissue	Percentage of total recovered
7	Skin	22.79
	Eyes	0.33
	Visceral organs	1.14
	Gills	10.11
	Muscle	3.01
	Skeleton	62.62
	Total	100.01

uptake apparently levels off at a value which corresponds to a concentration factor of about 0.3. This means that these fish can to some extent exclude the strontium ion in solution. Even the skeleton had not yet come to equilibrium with the radioactivity in the sea water. This may mean that only about 70 per cent of the strontium in the bone is readily exchangeable. The remainder may be firmly bound in a lattice or to an organic matrix which has a slow rate of turnover. It should be emphasized that these fish were mature.

Experiments done at the R.L.F.W.S. with Sr^{89} on post-larval flounders indicate that age and temperature influence the uptake of elements in solution. One group was kept at 20–22° C in sea water containing Sr^{89}, and another group at 8–12° C. The fish in both groups averaged 0.02 g. each. Figure 8 shows that strontium was taken up more rapidly at the higher temperature. Thus at one day, the fish at the lower temperature had less than one third of the radioactivity of the fish at the higher temperature. The graph also shows that very young fish continue to take up strontium from solution very rapidly at 14 days, while at 14 days the *Tilapia* had reached an apparent steady state condition.

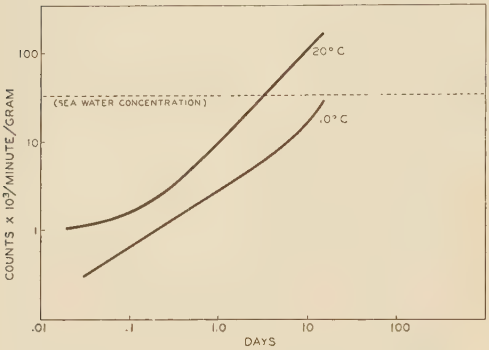

FIGURE 8. Uptake of Sr^{89} by Larval Flatfish.

The uptake of $zinc^{65}$ by croakers was studied at the R.L.F.W.S. These fish were fed the isotope in hardened gelatine. After 12 hours only about 27 per cent of the dose remained in the fish (Table 8). The distribution of zinc is quite different from that of strontium. About 90 per cent of the strontium retained by the various fishes used at the H.M.L. was found in the gills, bones, and integument. Zinc, however, is concentrated mainly in the liver and spleen. The muscle and bone, because of their bulk accounted for a large part of the total $zinc^{65}$ of the body. The turnover times of the zinc-containing compounds of the skin, muscle and bone were slow, whereas those of the internal organs were relatively rapid.

TABLE 8 $Zinc^{65}$ DISTRIBUTION IN CROAKERS (*Micropogon undulatus*) 12 HOURS AFTER ORAL ADMINISTRATION

Tissue or Organ	Per cent of total weight	Weight in grams	$Zinc^{65}$ mμc/gm.	$Zinc^{65}$ mμc per tissue or organ	Per cent of total body $zinc^{65}$
Muscle	80	48.80	1.6	78.1	44.7
Bone	11	6.71	5.5	36.9	21.1
Gills	2	1.22	10.9	13.3	7.6
Liver	0.8	0.49	40.7	19.9	11.4
Gonads	0.4	0.24	17.6	4.2	2.4
Kidney	0.3	0.18	41.5	7.5	4.3
Heart	0.2	0.12	14.0	1.7	1.0
Spleen	0.1	0.06	25.3	1.5	0.9
Remainder	5.2	3.17	3.7[1]	11.7	6.7
Skin, scales		——		——	
G I tract		60.99		174.8	
Blood					
Brain					
Eyes					
etc.					

[1] Based on skin and scales

Dose per fish—6,100 mμc
Distribution after 12 hours
Tissues 3 percent
G I tract 24 percent
Loss 73 percent (mostly excreted)

The uptake of radiocesium by fish was studied at the R.L.F.W.S. Table 9 shows the distribution of $cesium^{137}$ which was fed to little tuna. It can be seen that the liver, heart, spleen, and kidney rapidly take up the cesium, but these organs also lose the cesium during the following week. Muscle, gonad, brain, and skin, on the other hand, continue to accumulate the cesium faster than they lose it.

The accumulation of cesium in solution was demonstrated by keeping croakers in Cs^{137} enriched sea water. The water was changed daily to maintain a relatively constant concentration. Figure 9 indicates that during the 29 days, the heart, spleen, liver, brain, and muscle continued to accumulate the cesium. The concentration factor for the heart, spleen, and liver, was about 10, but this value is far below an equilibrium value.

TABLE 9 THE DISTRIBUTION OF $CESIUM^{137}$ IN THE TISSUES OF THE LITTLE TUNA AS A FUNCTION OF TIME

	Cs^{137} content in μc/g. wet wt.			
	Days after the dose			
Organ	1	3	6	8
Spleen	3.46	3.29	3.22	1.57
Liver	9.07	4.71	3.45	2.59
Kidney	3.13	2.58	1.78	0.95
Heart	6.17	3.15	2.52	1.57
Bone	0.41	0.40	0.17	0.26
Eye	0.30	0.26	0.31	0.30
Muscle	0.46	0.67	0.87	0.79
Gonad	0.54	0.70	1.33	1.34
Brain	0.30	0.35	0.69	0.66
Skin	0.29	0.46	0.41	1.01

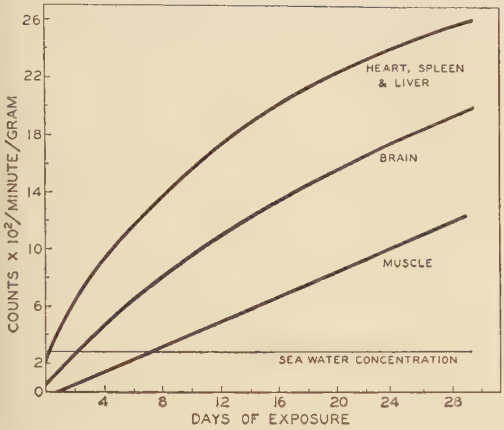

FIGURE 9. Accumulation of Cs^{137} by Croakers Kept in Sea Water Containing 5×10^{-3} Microcuries/Ml.

The relative concentration of cesium by the various organs is roughly the same for croakers, tuna, or bluefish. The same rank order among the organs is maintained both from ingestion, and from direct uptake.

Menhaden, a filter feeder, were put into sea water with $ruthenium^{106}$ that had been co-precipitated with calcium carbonate. Although a considerable amount of particle settling occurred, the menhaden took up the ruthenium in the digestive tract, but the tissues of the fish did not become radioactive to an appreciable extent. Similar experiments using menhaden fed with Ru^{106} labelled *Arbacia* plutei, or Ru^{106} labelled *Nannochloris* cells, gave parallel results. In the latter experiment the fish were allowed to eat the labelled cells for four hours, and then they were put in running sea water. At the time of transfer about 92 per cent of the ingested dose was found in the digestive tract. The gills had 0.64 per cent of the dose, and the remainder of the fish, including the skin, had 0.76 per cent. At 128 hours, only 0.05 per cent of the ingested dose remained in the digestive tract. There was 0.25 per cent in the fish body or on the skin surface, and 0.01 per cent in or on the gills. At no time was there an appreciable increase in the radioactivity of the body of the fish.

Toxicity of an Insecticide to Two Species of Shrimp, *Penaeus aztecus* and *Penaeus setiferus*

by **EDWARD CHIN** *and* **DONALD M. ALLEN**
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In the fall of 1956 mosquito control workers of Galveston County, Texas, received several reports from bait dealers in the Galveston Bay area that several days after aerial spraying of the surrounding marshes with insecticide, considerable mortality of live shrimp occurred in their bait pens. In this area and throughout the Gulf of Mexico live shrimp sold for bait are commonly held in wooden pens suspended in the waters of the bays and bayous. Mortality of shrimp in bait pens attributed by shrimp fishermen to aerial spraying of DDT has been reported in the Ft. Pierce region on the eastern coast of Florida by De Sylva (1954).

Biologists and conservation workers have been concerned with the effects of insecticides on beneficial forms, particularly since the increased use of these chemicals after World War II. Toxicity of various insecticides, especially DDT, to fish and wildlife has been investigated by a large number of workers and excellent references can be found in publications by George, Darsie, and Springer (1957), Cottam (1956), and Doudoroff, Katz, and Tarzwell (1953). With the exception of work by Springer and Webster (1951), Tiller and Cory (1947), and George, Darsie, and Springer (1957), studies have been confined largely to freshwater fishes, birds, and mammals. Little information is available concerning the effect of insecticides on the estuarine flora and fauna. Since considerable aerial spraying is done over salt water marshes, particularly in the South, such studies are especially appropriate.

The insecticide used in the Galveston area is Tri-6 Dust No. 30 (Thompson-Hayward Chemical Company, Kansas City, Missouri). It contains 3.0 per cent gamma isomer of benzene hexachloride, 5.1 per cent other isomers of benzene hexachloride, and 91.9 per cent inert ingredients. Benzene hexachloride and BHC are common names for 1, 2, 3, 4, 5, 6-hexachlorocyclohexane, a chemical frequently used in commercial insecticides. The material was tested in the experiments described below at the request and with the cooperation of William Cox, Director of the Galveston Mosquito Control District, to determine if it could be considered dangerous to populations of commercially important shrimp.

DETERMINATION OF LETHAL LEVELS

General Methods. Lethal levels were determined for two size groups of shrimp. The larger shrimp ranged from 29 to 50 millimeters in length with a mean of 41.6 millimeters and standard deviation of 5.9. The smaller shrimp ranged from 11 to 13 millimeters in length with a mean of 11.9 millimeters and standard deviation of 0.45. Lengths represent measurements from the tip of the rostrum to the end of the telson. Except where noted, concentrations are in terms of parts per billion (p.p.b.) Tri-6 Dust No. 30. For brevity, this material will be referred to as Tri-6 Dust. Sea water used to make up solutions was filtered through glass wool to remove detritus and macroscopic organisms. Salinities were determined chemically and are in terms of parts per thousand (p.p.t.). All pH readings were obtained at the start of each experiment with a Beckman pH meter. The experiments were conducted in close accordance with the bioassay methods suggested by Doudoroff *et al.* (1951). Due to the nature of the animals, however, certain aspects required modification.

Methods—29 to 50 millimeter size group. Varying quantities of sea water were placed in seven 2-gallon, covered, glass jars, 265 millimeters in height and 230 millimeters in diameter. All solutions were aerated until the experiment was terminated. Air stones used in preliminary experiments showed some evidence of prolonged or permanent contamination with Tri-6 Dust and were replaced with disposable glass pipettes. Six shrimp were placed in each of the seven jars. With the exception of two specimens of *Penaeus aztecus*, all shrimp of this size group were *Penaeus setiferus*. After approximately two hours, additional sea water containing 1000 p.p.b. Tri-6 Dust was added to six of the seven jars to make up seven liters of sea water with resultant concentrations ranging from 2.5 p.p.b. to 100 p.p.b. The seventh jar containing seven liters of sea water was used as a control.

The temperature of the water in the jars remained constant at 26.0° C. throughout the course of the experiment. The salinity of the sea water used to make up the solutions was 31.2 p.p.t. and pH values of the seven solutions ranged from 8.15 to 8.25. Due to the cannibalistic nature of the animals, all were fed with small amounts of fish.

Methods—11 to 13 millimeter size group. The smaller shrimp were exposed to varying concentrations of Tri-6 Dust in a similar manner. The total volume in each two-gallon jar was reduced to four liters and concentrations ranged from 0 to 1500 p.p.b. Previous experience has shown that there is considerable tendency for shrimp of this size to jump out of the water and become fixed to the sides or covers of the jars. To eliminate accidental mortality of this type, the shrimp were placed in 500-milliliter covered, plastic dishes perforated with small holes. Ten small shrimp were placed in each dish and the entire dish was immersed in the four liters of solution. The large number of perforations in the plastic dishes and the agitation of the water due to aeration and activity of the animals permitted a free exchange of fluid between the dish and the surrounding medium.

Temperature of the water in the jars rose gradually from 17.4° C. to 22.3° C. during the experiment. Salinity was 31.4 p.p.t. and pH values of the solutions ranged from 8.15 to 8.2. All shrimp were fed with small quantities of ground veal sold for use as baby food.

Penaeid shrimp less than 15 millimeters in length are difficult to identify and a large sample of the stock from which the experimental animals were drawn was reared to a more advanced stage in the laboratory. This group was comprised entirely of *P. aztecus*.

Results. The results shown in figures 1 and 2 indicate clearly that shrimp are highly sensitive to Tri-6 Dust. In the 29 to 50 millimeter size group mortality was absent in the control jar and at concentrations of 2.5 p.p.b. and 5 p.p.b. At 10 p.p.b. and 25 p.p.b. mortality was negligible. However, at 50 p.p.b. and 100 p.p.b. mortalities of 83 per cent and 100 per cent, respectively, were noted.

In the 11 to 13 millimeter size group mortality was absent in the control jar. At 75 p.p.b. and 125 p.p.b. mortalities of 50 per cent and 80 per cent, respectively, were noted. At all other concentrations tested, 100 per cent mortality occurred.

From the results in figures 1 and 2 differences in sensitivity may exist between the two groups of shrimp. Of the larger shrimp, 83 per cent died at 50 p.p.b. compared to 50 per cent of the smaller shrimp at 75 p.p.b. Differences in sensitivity to the insecticide were demonstrated, also, by a comparison of the estimated 24-hour median tolerance limits. The median tolerance limit (TL_m) or the concentration at which 50 per cent of the test animals are able to survive for a specified period of exposure as suggested by Doudoroff *et al.* (1951) was adopted to derive an index of relative toxicity. Figure 3 shows that the estimated 24-hour TL_m for the smaller shrimp was approximately 400 p.p.b. compared to 35 p.p.b. for the larger shrimp.

Since the larger shrimp were composed almost entirely of *P. seti-*

ferus while the smaller shrimp were composed of *P. aztecus*, differences in sensitivity to Tri-6 Dust could be related either to differences between species or between size groups. Other experiments not reported here indicate that there is no appreciable difference between comparable sizes of the two species in susceptibility to the insecticide. The observed differences, therefore, are attributed to size rather than species differences.

STABILITY OF TOXIC FACTOR

Methods. Since all insecticides have a limited effective life we were interested in the stability of the toxic factor or factors in solution when exposed to sunlight. Four 5-gallon pyrex carboys, containing 14 milligrams of Tri-6 Dust in 14 liters of filtered sea water, were placed outdoors, one every four days for 12 days. The insecticide was added just prior to setting each solution outdoors. Thus, 18 days after the initial carboy was established, we had four solutions, each containing 1000 p.p.b. Tri-6 Dust, that had been exposed to sunlight for 6, 10, 12, and 18 days, respectively. The solutions were tested on the eighteenth day and compared with a fresh solution of equal concentration.

Seven liters of each solution were placed in 2-gallon, covered, glass

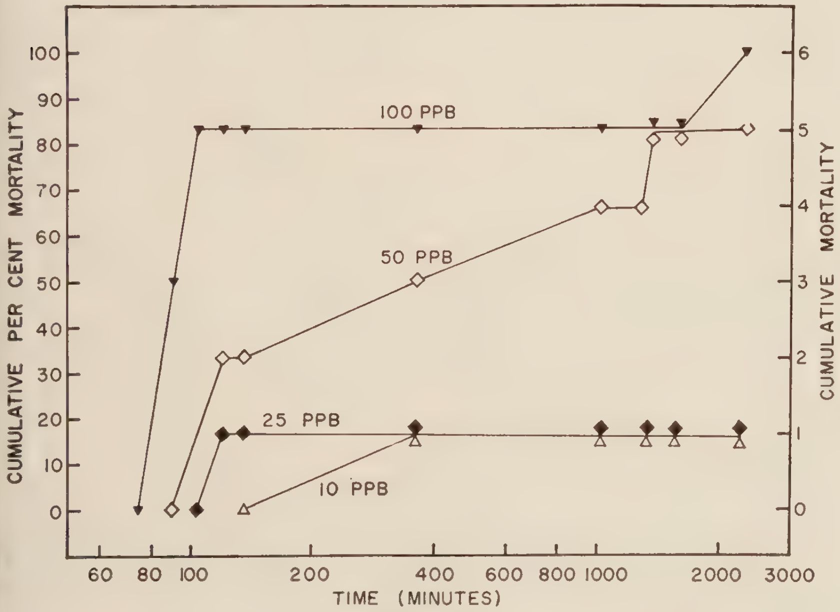

FIG. 1 MORTALITY OF SHRIMP (29-50 MM. SIZE GROUP) AT FOUR CONCENTRATIONS OF TRI-6 DUST.

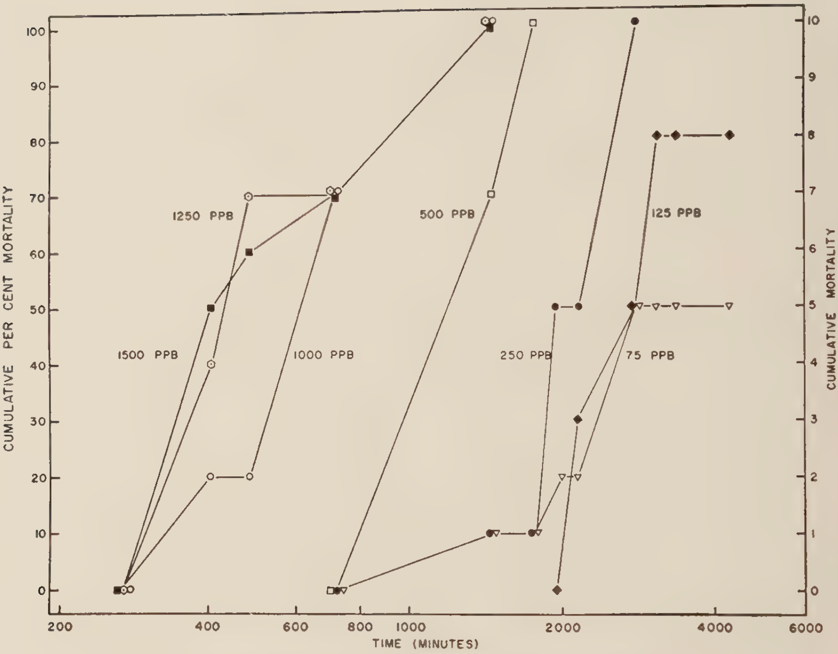

FIG. 2 MORTALITY OF SHRIMP (11-13 MM. SIZE GROUP) AT SEVEN CONCENTRATIONS OF TRI-6 DUST

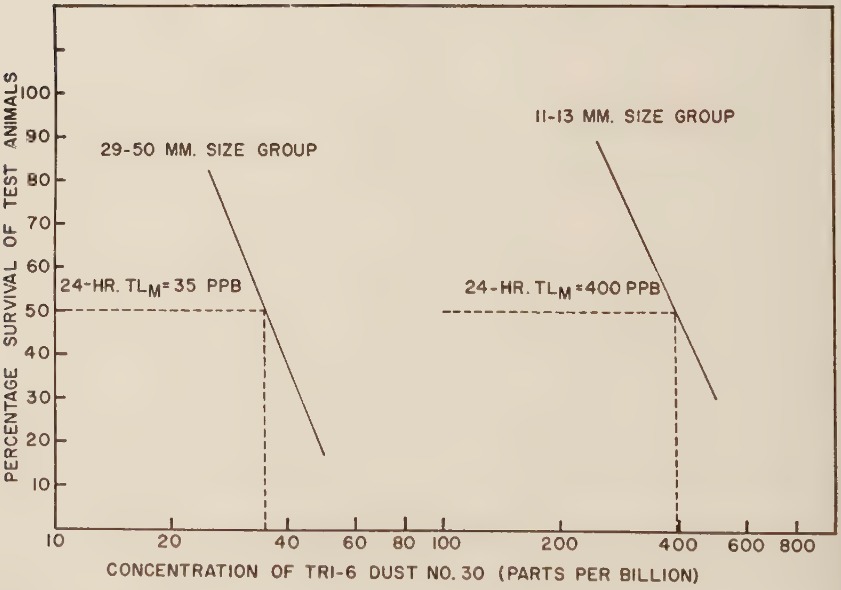

FIG. 3 ESTIMATION OF 24-HR. MEDIAN TOLERANCE LIMITS BY STRAIGHT-LINE GRAPHICAL INTERPOLATION FOR TWO SIZE GROUPS OF SHRIMP.

jars. A control jar was established and six shrimp were immersed in each solution. The shrimp included two species, *P. setiferus* and *P. aztecus*, and ranged in length from 39 to 65 millimeters with a mean of 56 millimeters and standard deviation of 6.4. Water temperatures ranged from 21.5 to 22.5° C. during the experiment. Salinity of the water used to make up the solutions was 31.3 p.p.t. and pH values of the six solutions ranged from 8.0 to 8.2. As in the other experiments, all solutions were aerated.

Results. With the exception of the control group in which no mortality occurred, 100 per cent mortality occurred in all jars within 24 hours. Exposure to sunlight up to 18 days had no apparent effect on the toxicity of the insecticide. Fifty per cent of the test animals at each concentration became moribund within one hour and mortality proceeded at approximately the same rate.

FIELD TEST

A field test was conducted with the cooperation of the Galveston Mosquito Control District. Minnow traps containing shrimp were placed in a bayou near Texas City. The test area received a direct application of Tri-6 Dust from a low flying airplane. Mortality was negligible in all traps. Results were considered inconclusive, however, as the insecticide remained at the surface, and drifted away from the test area through the combined action of the wind and tide. When insecticides are applied over water, it is difficult to evaluate their effects on aquatic organisms without considering tides, currents, wind, depth of water, and other factors.

DISCUSSION AND CONCLUSIONS

Although the field test was inconclusive, results of the laboratory experiments show clearly that Tri-6 Dust can be considered extremely toxic to shrimp. Since 91.9 per cent of the compound consists of inert ingredients, mortalities of 83 per cent of the larger shrimp at 50 p.p.b. and 50 per cent of the smaller shrimp at 75 p.p.b. were caused by actual concentrations of 4 and 6 p.p.b. benzene hexachloride, respectively.

The inverse relationship between size of shrimp and resistance to Tri-6 Dust can be explained, possibly, on the basis of differences in total volume of solution. The smaller shrimp were exposed to a total volume of four liters compared to seven liters for the larger shrimp. Prévost, Lanouette, and Grenier (1948) showed that per cent mortality of fish at a given concentration of DDT increased with an increase in volume of solution. Saila (1953) reported a similar increase in mortality using rotenone as a toxicant. A factor that deserves consideration, however, is the size of the experimental animals. The average weight of the smaller shrimp was .06 gram compared to approximately one gram for the larger shrimp. Thus, on the basis of unit weight the smaller shrimp were exposed to a considerably larger volume of solution.

The stability of the toxic factor or factors requires further investigation. In our experiments, exposure of several 1000 p.p.b. solutions of Tri-6 Dust to sunlight for periods up to 18 days had no apparent effect on the toxicity of the insecticide to shrimp. Since the observed tolerance levels are extremely low, the stability of weaker solutions should be studied.

Evaluation of the effects of insecticides to estuarine organisms under actual conditions is difficult. The Galveston unit has constantly made efforts to avoid dispersing insecticide over water. Nevertheless, fish kills in 15 streams in the Tennessee Valley of Alabama have been attributed by Young and Nicholson (1951) to organic insecticides that were washed into the streams from the soil and vegetation by heavy rains. In seaside areas heavy rainfall and or a series of high tides could wash deposits of insecticide from the marshes and rice fields into the bayous and estuaries with possible disastrous effects for certain organisms.

Insect control in estuaries and surrounding marshlands presents a problem often faced by entomologists, fishery biologists, and mosquito control workers. These areas are well known breeding grounds for several species of mosquitoes and at the same time are used as nursery grounds by many fish and aquatic invertebrates. Among these are the shrimp tested in the above experiments. Shrimp, presently the country's most valuable fishery product in terms of dollar volume sales, spend several vital months in the bayous and estuaries of the Gulf shortly after hatching. The importance of suggestions and precautions on the application of insecticides by Springer and Haugen (1953), Linduska and Surber (1948) and other workers in the field is obvious.

SUMMARY

Tri-6 Dust No. 30 (Thompson-Hayward Company, Kansas City, Missouri), an insecticide used extensively by mosquito control workers in Galveston County, Texas, was tested in the laboratory to determine if it could be considered toxic to commercially important shrimp. The material contains 3.0 per cent gamma isomer of benzene hexachloride, 5.1 per cent other isomers of benzene hexachloride, and

91.9 per cent inert ingredients. Lethal levels were determined for two size groups of shrimp. The larger shrimp ranged from 29 to 50 millimeters in length and consisted almost entirely of *Penaeus setiferus*. The smaller shrimp ranged from 11 to 13 millimeters in length and consisted entirely of *Penaeus aztecus*. A mortality of 83 per cent at 50 parts per billion was noted for the larger shrimp compared to 50 per cent at 75 parts per billion for the smaller shrimp. The apparent greater sensitivity of the larger shrimp to the insecticide was demonstrated, also, by estimated 24-hour median tolerance limits of 35 parts per billion compared to 400 parts per billion for the smaller shrimp. Differences in sensitivity were attributed to size, rather than species differences. Up to 18 days of exposure to sunlight had no effect on the stability of the toxic factor or factors. A field test was conducted, but results were inconclusive. Nevertheless, laboratory experiments show clearly that Tri-6 Dust No. 30 should be considered extremely toxic to shrimp.

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Some Biochemical Aspects of Red Tides and Related Oceanographic Problems[1]

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ABSTRACT

"Red Tides" are blooms of plankton organisms which may or may not be lethal to aquatic organisms. The sudden increase in multiplication rates of the organisms is caused by a complex of biological factors, and physical factors play a major role in effecting mechanical concentration.

This paper deals with the biological factors operative in the genesis of blooms. Nutritional studies show that organic factors which occur naturally in the water are important. The existence of biologically active organic compounds and possible modes of action are discussed. The method of measurement of "carbohydrates" is explained and their production by bacteria-free cultures of *Prorocentrum* is demonstrated. Such organic compounds could serve as substrates for vitamin B_{12}-producing bacteria and thus play a role in the conditioning of water for succeeding populations.

Gymnodinium breve, the causative organism of the Florida Red Tide, responds differentially to Gulf of Mexico waters of different origins. A suggested explanation is the interaction between environmental copper and hydrogen sulfide. Once started, a bloom may replenish the required nutrients by the decomposition of the fish that it kills.

INTRODUCTION

"Red Tide" is a popular term applied to unusual concentrations of freshwater or marine organisms—protozoans or unicellular algae—which may or may not cause a red discoloration of the water, and which may or may not be lethal to fish or other aquatic organisms. In recent years the phenomenon has become widely known and the term much used because of some highly publicized and spectacular fish kills. The explanation of the genesis of these blooms is to be found in the physiology and related environmental responses of the organisms concerned, while the extent of resulting fish kills is dependent upon their concentration. Biological and chemical factors are most critical in determining the environmental responses of the causative organisms, while physical factors are the most important concentrating agents.

The mechanics of concentration of semibuoyant particles drifting in the open sea can be explained by such devices as convergence of water masses, wind-driven surface currents, and convection cells. Various authors have treated these systems in theoretical terms, and Ryther (1955) has reviewed them in the light of the present knowledge of dinoflagellate nutrition. He concluded, "It is necessary only to have conditions favoring growth and dominance of a moderately large population of a given species and the proper hydrographic and meteorological conditions to permit the accumulation of organisms at the surface and to effect their further concentrations in localized areas."

The U. S. Fish and Wildlife Service has concentrated on the study of the biological processes that stimulate plankton blooms, and the collection of field data necessary for the interpretation of laboratory results. The following is a review of some of our more recent findings of general interest and a discussion of the relations between the natural organic compounds in sea water and plankton blooms. Specific oceanographic aspects will be emphasized.

I wish to acknowledge the work of my colleagues, Mr. J. O. Bell, Mr. Alexander Dragovich, Mr. K. T. Marvin, Dr. Sammy Ray, Dr. T. J. Starr, Mr. W. B. Wilson, and Mrs. Zoula Zein-Eldin, who have made

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contributions to the information used in this paper.

NUTRITIONAL STUDIES ON DINOFLAGELLATES

Although we are studying the nutrition of dinoflagellates in general, our initial attempts concerned the isolation and continued culture of *Gymnodinium breve*, the causative organism of the Florida Red Tide (Wilson and Collier 1955, Ray and Wilson 1957). The composition of the most useful medium, and one which we are still using, is given in Table 1.

With this as a starting point we progressed from unialgal cultures to bacteria-free cultures (Ray and Wilson 1957) and have worked intensively to derive a defined medium. Many workers have put much effort into this problem, using a variety of organisms (Pringsheim 1946, Barker 1935, Hutner and Provasoli 1955, and Provasoli and Pintner 1953). Optimum limits for inorganic salts, trace metals, vitamins, amino acids, and miscellaneous growth factors have been determined empirically. Even with all this information and the results of our own work we are still left with the conclusion that some sea waters contain organic materials that make the addition of soil extract or vitamin B_{12} unnecessary.

TABLE 1. *Medium for the unialgal isolation of* G. breve *Davis*

After all additions are made, there is approximately 110 ml of medium.

(After Wilson and Collier 1955)

Aged sea water (salinity, about 36.5 ‰)	95.0 ml
Distilled water*	5.0 ml
NH_4Cl†	0.1 mg
KH_2PO_4†	0.05 mg
$MgCl_2 \cdot 6H_2O$†	0.02 mg
$Na_2S \cdot 9H_2O$†	0.1 mg
$NaHCO_3$†	0.1 mg
Vitamin B_{12}	0.1 μg
Thiamine hydrochloride	1.0 mg
Biotin	0.05 μg
Soil extract‡	2.0 ml
EDTA·Na (6 ml of 0.25-percent solution)	15.0 mg

* More or less may be required, depending on the salinity.

† Added as 0.5 ml of the following solution of the components of van Niel's medium for sulfur bacteria: NH_4Cl, 0.2 g; KH_2PO_4, 0.1 g; $MgCl_2 \cdot 6H_2O$, 0.04 g; $NaHCO_3$, 0.1 g; and $Na_2S \cdot 9H_2O$, 0.2 g to 1 liter of distilled water.

‡ Simmer for 40 min a mixture of 500 g of garden soil and 1 liter of distilled water. Let it stand for 4 days and decant the supernatant. Repeat simmering and decantation until extract is clear. Use the supernatant.

Thus we became concerned with the biological controls which systems of aquatic organisms can exert on each other through the intermediary of organic substances. Through metabolites exuded by living cells, or decomposition products from dead cells, a population may exclude other populations, or promote or inhibit the growth of succeeding populations (Stevens 1949, Wilson 1951, Lucas 1949, and Collier 1953).

THE DEMONSTRATION OF BIOLOGICALLY ACTIVE COMPOUNDS IN SEA WATER

Collier *et al.* (1953), using a modified Dische reaction (Erdman and Little 1950), reported carbohydrate-like materials which quantitatively affected the pumping rate of oysters, and whose concentration in untreated water was influenced by light. They varied in concentrations from zero to over 20 milligrams per liter in the estuary studied. Wangersky (1952) reported the identification of dehydro-ascorbic acid and a rhamnoside from natural sea water. High concentrations of carbohydrates were found in rich marsh waters and in extreme concentrations of plankton organisms associated with a red tide outbreak in Florida (Collier 1953). These latter values were on the order of 50 mg per liter.

Interesting results of the study of the specific effects of commercially prepared organic compounds on various organisms were the motor responses elicited in oysters and barnacles by niacinamide and ascorbic acid, respectively (Collier *et al.* 1956). The effective concentrations were 0.042 mg per liter of sea water for niacinamide and 0.014 mg per liter for ascorbic acid. This is a further demonstration of the potential role of organic compounds in the marine community.

THE MEASUREMENT OF "CARBOHYDRATES" IN NATURAL SEA WATER

Before discussing the distribution of organic substances in the Gulf of Mexico and their production in laboratory cultures some analytical details should be clarified. The use of N-ethyl carbazole for the quantitative estimation of carbohydrates in marine waters was originally described by Erdman and Little (1950) and has been improved by Zein-Eldin and May (1957). Some time ago we found that in the waters with which we were working anthrone did not provide the sensitivity of N-ethyl carbazole, and as a result we adopted the latter as our standard reagent.

The analytical results are reported in terms of "milligrams per liter (arabinose equivalent)," but will be referred to hereafter as simply "carbohydrates." The reason for this is that we do not know what specific compounds are being measured, but only that on the hydrolysis of a sample we get a color response which can be quantitated according to Beer's Law. Zein-Eldin has plotted a series of absorption curves for a variety of hexoses and pentoses, and she kindly provided me with the figures used here to compare hexose and pentose curves with those obtained from naturally produced substances.

The absorption curve for a bacteria-free culture of *Prorocentrum* sp. is compared with the curves for arabinose and sucrose in Figure 1. The original traces were made with a recording spectrophotometer. The curve made from the culture clearly indicates a mixture of pentoses and hexoses.

The origin, significance, and molecular structures of these compounds raise some questions which need to be answered. Lewis and Rakestraw (1955) found that filtered samples of sea water do not yield significant quantities of carbohydrate in the Pacific. On the other hand, Plunkett and Rakestraw (1955) show heterogeneous distribution of dissolved organic materials in the Pacific as determined by Krogh's method for organic carbon. They considered these differences significant and concluded that since these materials represent the largest fraction of total organic matter in the sea, more intensive investigation is needed. Kay (1954), using the determination of elemental organic carbon, found a situation in the Kielerbucht similar to that reported by Plunkett and Rakestraw. After discussing his findings and pointing out conflicting arguments, he concluded that the whole matter must await clarification of the exudation of organic metabolites by the plankton organisms, particularly the algae. He considered the latter to be a plausible source of dissolved organic compounds in the sea. Vallentyne (1957) has given a comprehensive review and classification of organic compounds reported in the literature.

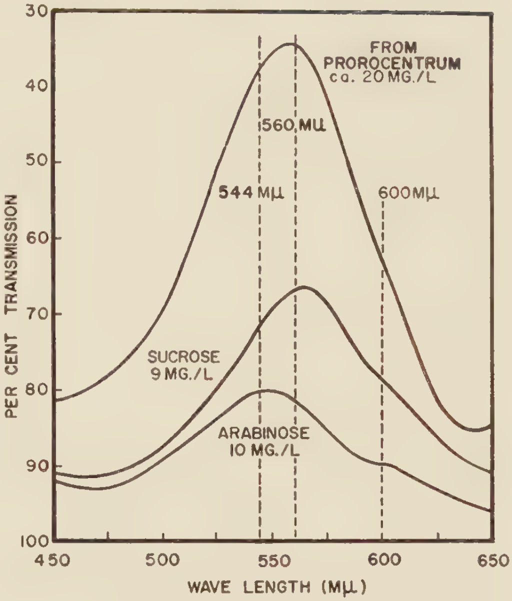

FIG. 1. Photometric responses of sucrose, arabinose, and culture of *Prorocentrum* sp. after treatment with N-ethyl carbazole. Concentrations are indicated on curves. Traces were made with recording spectrophotometer.

PRODUCTION OF ORGANIC SUBSTANCE IN LABORATORY CULTURES

In the preceding section I offered evidence that the carbohydrate responding to N-ethyl carbazole and produced by a single, specific organism in bacteria-free culture could be qualitatively classed with known sugars.

To understand the significance of measurements of these compounds made on samples from natural environments we should have some idea of the quantitative aspect.

For this purpose I present some results from studies on a 16-liter, unialgal (not bacteria-free) culture of *Prorocentrum* sp. which contained approximately 2.8 million cells per liter. The organisms were separated from the medium with a high-speed continuous-flow centrifuge. Although bacteria were present, it is doubtful that they contributed greatly to the carbohydrate values when *Prorocentrum* was by far the dominant organism. This situation is similar to that found by Goldberg *et al.* (1951) in their study on phosphate utilization by diatoms. Five independent carbohydrate determinations were made for the centrifugate, the residue, and the basal medium. The means of these determinations and their respective standard deviations are given here. A mean value of 0.72 ± .22 mg/L is given for the basal medium. This initial quantity is not subtracted from the final results because of the likelihood that it served as a carbon source for the organisms in the culture and was redistributed between them and their metabolites. The mean carbohydrate value for the whole culture was 9.58 ± .48 mg/L, and for the centrifugate 5.84 ± .44 mg/L. The mean difference of 3.74 ± .46 mg/L represented the portion of the material retained by those organisms not passing through the centrifuge. The total carbohydrate in the centrifugate was about 60% of that in the original culture, and estimating 10% of this as originating in crushed organisms or those not retained in the residue, this culture produced approximately 2 mg of non-particulate carbohydrate per million cells. In terms of the whole culture the production was 3.4 mg of carbohydrate per million cells. Similar experiments with *G. breve* and *Gymnodinium splendens* gave values of 2 mg and 1.6 mg, respectively, for the centrifugates. We cannot rely on either of the latter because the organisms were too fragile for an evaluation of their resistance to the mechanical effects of centrifuging. *Prorocentrum* is an armoured dinoflagellate and is more resistant than the naked forms mentioned above.

Lewin (1956) found that *Chlamydomonas mexicana* nom. prov., a mucilaginous fresh-water flagellate, liberated as much as 0.1 gram per liter of soluble polysaccharide into the culture medium. This material constituted 20–25% of the total organic matter produced. While these values cannot be compared to our results from the *Prorocentrum* cultures, they indicate the magnitude of the potential role of algae in producing free organic substances in the aquatic environment.

THE DISTRIBUTION OF CARBOHYDRATES IN THE COASTAL AND ESTUARIAL WATERS OF THE GULF OF MEXICO

In earlier work Collier *et al.* (1953) found that carbohydrates in marsh waters fluctuated between zero and 25 mg/L. Such a range should have been expected in an area which was influenced both by the carbohydrate-poor waters of the open Gulf of Mexico and some highly productive marsh areas. The same work also showed a clear diurnal cycle of concentrations, with the maximum coming at midafternoon and the minimum after midnight. In samples taken from the high concentrations of *G. breve* in a red tide I reported (1953) some 50 mg of crystalline material per liter of water. This is not out of line with 44 mg/L of carbohydrates measured in a 16-liter unialgal (not bacteria-free) culture of *Prorocentrum*. Our evidence supports the idea that, in surface waters at least, some of these substances are produced by photosynthetic organisms, and when such organisms are in sufficiently dense aggregations, significant quantities of these substances will be indicated by the N-ethyl carbazole reaction.

The patchiness or highly uneven distribution of organisms in marine waters is well established (Barnes and Marshall 1951, Bainbridge 1953), and if the carbohydrates are associated with such aggregates of photosynthetic organisms we should find them similarly distributed.

In a series of oceanographic cruises in the Gulf of Mexico by the U. S. Fish and Wildlife Service research vessel Alaska samples for the determination of carbohydrates, tyrosine, and organic phosphorus were collected at depths ranging from the surface to 2500 meters at stations distributed over the entire Gulf. There were over 800 determinations each of carbohydrate, tyrosine, and organic phosphorus in this series. A detailed study of this investigation will appear elsewhere, but it is helpful to present some of this information here to indicate how consistent are the results of organic analyses with heterogeneous plankton distribution.

On one of the cruises ALASKA encountered an area of steep salinity gradient that was indicative of a convergence of two dissimilar water masses. In the area there was "red water" caused by a heavy concentration of a ciliate, probably *Mesodinium pulex* (Slobodkin 1953). This bloom was well offshore and bore no resemblance to a fish-killing red tide such as is caused by *G. breve*. The concentration of the organisms is consistent with the mechanisms surveyed by Ryther (1955). In samples of water collected from this station (preserved by quick freezing and neither filtered nor centrifuged) we got the following values: carbohydrates 3.6 mg/L, tyrosine 1.4 mg/L, and organic phosphorus 6.7 microgram-atoms PO_4-P/L. At a station in clear water outside of the ciliate concentration we obtained the following values: carbohydrates 0.0 mg/L, tyrosine 0.3 mg/L, and organic phosphorus 1.0 microgram-atoms PO_4-P/L. These differences demonstrate the association of high carbohydrates, tyrosine, and organic phosphorus values with high concentration of organisms.

Table 2 illustrates the frequency distribution of carbohydrates, tyrosine, and organic phosphorus in all samples taken within the 100-fathom curve by M/V ALASKA. By inspection one can see that these distributions are similar to those shown by Barnes and Marshall (1951) to characterize plankton aggregations. This similarity may be interpreted to mean that the concentration of organic substances represented by the carbohydrate, tyrosine, and organic phosphorus tests were generally low, but when they did occur the concentrations were relatively high, or, in other words, there was a tendency towards the contagious distribution (Barnes and Marshall 1951).

TABLE 2. *Frequency distributions of carbohydrates, tyrosine, and organic phosphorus for samples collected over continental shelf of Gulf of Mexico by M/V Alaska*

Carbohydrates			Tyrosine			Organic Phosphorus		
mg/L	*n*	%	mg/L	*n*	%	μg-at. PO_4-P/L	*n*	%
.0	68	23.2	.0	63	19.7	.0	13	6.7
.2	37	12.6	.2	73	22.8	.2	35	18.1
.4	41	14.0	.4	63	19.7	.4	34	17.6
.6	32	11.0	.6	41	12.8	.6	32	16.6
.8	24	8.2	.8	32	10.0	.8	31	16.1
1.0	22	7.5	1.0	11	3.4	1.0	15	7.8
1.2	20	6.8	1.2	16	5.0	1.2	11	5.7
1.4	10	3.4	1.4	10	3.1	1.4	3	1.6
1.6	14	4.8	1.6	3	0.9	1.6	0	—
1.8	8	2.7	1.8	6	1.9	1 8	4	2.1
2.0	7	2.4	2.0	2	0.6	2.0	4	2.1
2.2	1	0.3	—	—	—	2.2	5	2.6
2.4	2	0.7	—	—	—	2.4	2	1.0
2.6	3	1.0	—	—	—	2.6	2	1.0
2.8	2	0.7	—	—	—	2.8	0	—
3.0	2	0.7	—	—	—	3.0	2	1.0
	293	100.0		320	99.9		193	100.0

ORGANIC COMPOUNDS AND RED TIDES

We may now deal more specifically with the Florida Red Tide. Over a period of several months a series of stations along the Florida coast has been sampled for carbohydrates, proteins, and other chemical entities. These data will receive a more detailed treatment elsewhere, but I would like to mention some of the outstanding features of the analysis in terms of the genesis of red tides.

There were 184 pairs of protein and carbohydrate determinations used in this study. The extremes of carbohydrate values were 0.0 and 19.4 mg per liter; of tyrosine, 0.0 and 2.9 mg per liter. The highest concentrations in both cases were found in rivers, tidal streams, and marshes bordering the estuaries; the concentration generally diminished in a seaward direction, with the lowest values occurring in the offshore waters of the Gulf. The latter were within the general range of the quantities reported from the ALASKA cruises.

At this point the most important feature is the erratic nature of the distributions of these two classes of compounds and, as pointed out above, the probability that they are directly related to the distribution of microplankton.

Organic compounds provide a substrate for bacterial activity and can serve as growth promoters for animal and plant components of the plankton. A bloom of algae can charge the water with sufficient organic material to support a growth of bacteria and/or to condition the water for succeeding species. We have found that a particular bacterial colony type always associated with our unialgal cultures of *G. breve* as the dominant bacterium is a producer of vitamin B_{12}, a growth promoter. This bacterium will not develop to a position of dominance in the absence of *G. breve*. Here, then, is at least an experimental system in which the alga is probably supplying an organic substrate which indirectly conditions the water for its own growth. In combination with the distribution of organic compounds detailed above, this observation leads to some experiments similar to those conducted by Wilson (1951). The following is the summary of his paper: "Eggs and larvae of *Echinus esculentus*, *Ophelia bicornis* and *Sabellaria alveolata* developed abnormally, or were in poor health, in seawater collected from the English Channel in the region of the Eddystone, although in water collected from the Celtic Sea development was generally normal and healthy. Experiments indicated that the Channel water lacked some unknown constituent, essential for healthy development of these species, present in the Celtic Sea. The results accord with some of the hydrographical and biological changes in the area which have taken place within recent years."

Mr. W. B. Wilson of our laboratory at Galveston has been conducting growth experiments with cultures of *G. breve* using sea water collected at different times from various points as a base for his culture media. At one extreme some of these waters are outright toxic to the organisms, and at the other the waters will support luxuriant growth with no supplementary additions. There are intermediate types which cause response after treatment with additives ranging from a single item of the above formula (Table 1) to the whole list. The extremes may come from samples collected at the same time only a few miles apart.

We have found that sulfides will substitute for organic chelators and that copper is highly toxic to *G. breve*. Sulfides were used in the original medium for the artificial culture of *G. breve* (Table 1). The mangrove-covered marshes that border the estuaries of the Florida west coast are prolific producers of hydrogen sulfide, and the natural copper concentration in the coastal waters is extremely variable. The interplay of these two factors is possibly active in establishing the level of toxicity of untreated sea water to this and other organisms. An additional factor may be the action of natural organic compounds as chelators, because they themselves can act as copper binders. Thus it may be possible for them simultaneously to detoxify water and to furnish growth promoters for the more sensitive members of the marine plankton.

A constant surveillance in Florida waters over the past three years has shown that *G. breve* is present in very low concentrations at one point or another along the Florida coast most of the time. Mr. W. B. Wilson has successfully isolated and cultured the organism from waters within the city limits of Galveston, Texas. Wilson and Ray (1956) found blooms of the same organism associated with large fish kills off the South Texas and Mexican east coasts, and again it was successfully isolated and cultured. From these findings we conclude that the organism may normally exist over a considerable geographic range in very low numbers.

Its sensitivity to unfavorable conditions keeps it in check and prevents a more frequent occurrence of Red Tides. However during the rainy season the introduction of large volumes of land drainage with heavy loads of organic materials can provide the initial stimulus for heavy blooms of the organism, which in turn may augment themselves with both inorganic and organic materials produced by the decomposition products of dead fish (Wilson and Collier 1955).

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4

SIX YEARS OF CATCH STATISTICS ON YELLOWSTONE LAKE

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Abstract

The U. S. Fish and Wildlife Service collected catch statistics on Yellowstone Lake and adjacent waters from 1950 to 1955 as part of an investigation on the status of the cutthroat trout fishery and the fish populations. Methods for estimating numbers of fishermen, hours of effort, and catch, were developed for each unit of the fishery and were used to compute estimates for all years of the 6–year period.

One feature of this fishery is the presence of only one species of sport fish in these waters. Another is an unusual hourly distribution of fishing throughout the day. Very little fishing is done before 7 a. m. and thereafter three peak periods of fishing effort occur, in the late morning, in the afternoon, and in the evening. Another characteristic is a remarkable uniformity of angling pressure among days of the week. The "resort" character of the Yellowstone situation explains these unusual tendencies. Good opportunity also is afforded in this fishery for studies on the effects of changes in regulations.

Distribution of fishing effort according to area and season has been very constant from year to year. The Fishing Bridge fishery peaks early in the year and declines rapidly. The West Thumb fishery is smaller, but is sustained throughout the season. The lake outlet area accounted for 30 percent of the total catch of Yellowstone Lake, and 27 percent of the combined lake and river catch. The components of the fishery contributed the following average annual catches: West Thumb Dock guides and rowboats, 25,450 fish, or 9.98 percent of the lake total; Fishing Bridge Dock guides and rowboats, 54,239 fish, or 21.27 percent; Lake Dock guides and rowboats, 33,387 fish, or 13.09 percent; lake shoreline, 65,271 fish, or 25.60 percent; Fishing Bridge 6,474 fish or 2.53 percent; private boats, 70,123 fish, or 27.50 percent. The average annual lake catch for the 6–year period was 254,944 fish. The average catch in the river was 33,575 or 13.16 percent of the lake catch.

Trends for the lake and river fishery as a whole show an increase in fishing effort up to 1952, followed by a small reduction in 1953 and increases in 1954 and 1955. Fishing effort varied with the numbers of tourists, although the reduction in fishing pressure from 1952 to 1953 was greater than the reduction in numbers of tourists. The successes of individual components of the fishery have fluctuated independently of each other from year to year. The catch per fisherman hour for river and lake combined in 1955 was 0.671 fish, compared with 0.510 in 1951, 0.519 in 1952, 0.508 in 1953, and 0.584 in 1954.

Reductions in mean lengths of the catch were evident up to 1952. The mean lengths were greater for 1953–1955 than those of 1952, a condition that is attributed to weak year classes.

The reduction of the limit from five to three fish in 1953 did little toward reducing total catch, but the shortened season had a decided effect on the reduction of the catch.

Introduction

The cutthroat trout (*Salmo clarki lewisi*) fishery on Yellowstone Lake and River in Yellowstone National Park, Wyoming, has been under investigation by the U. S. Fish and Wildlife Service for several years. The

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postwar upsurge in the popularity of the fishery, with attendant apprehension that its stability might be threatened, was the occasion for intensifying the studies in 1950. The present program of investigation was organized in that year, with the cooperation of the U. S. National Park Service, which manages the Yellowstone lands and waters. The purpose of the study has been to determine the characteristics of the fish populations and of the fishery so that recommendations for maintaining the fish stock could be presented to the National Park Service for its consideration.

The creel census has been a primary feature of the investigation. The census of 1950 covered the fishery of Lake Yellowstone, and was succeeded the following year by an expanded and intensified census that included the 15 miles of Yellowstone River between Fishing Bridge and Canyon (Fig. 1). A report on the 1950 and 1951 census has been published (Moore, Cope, and Beckwith, 1952). Considerable detail concerning census methods, characteristics of the populations, the program, the fishery, and estimates of fishing effort, catch, and numbers of anglers were included. The mathematical basis for the census on the lake shoreline and the river was emphasized in the second part of the paper. Variance estimates for catch and effort were computed for the shoreline and river fisheries. A few of the estimates reported in the paper are included here but are slightly modified on the basis of later information.

The present paper, in addition to bringing together data collected during the 6–year period from 1950 to 1955, emphasizes the features of the fishery and the populations of Yellowstone Lake to bring out the significance of the study. The value of this effort lies not so much in the presentation of estimates of catch and effort as in the accentuation of the unique aspects of the fishing patterns in these waters. The creel census results are of course extremely important for the control of the fishery, but the occasion for this paper is the existence of unusual circumstances affecting the distribution of catch and the regulation of the fishery.

One of the important characteristics of the Yellowstone Lake fishery is the presence of only one species of sport fish. Two species of cyprinids and the longnose sucker (*Catostomus catostomus*) also occur in this drainage, but the Yellowstone cutthroat comprises virtually the entire catch. In terms of management of a resource this is a unique situation.

Another feature of the fishery is the "resort" character of the accommodations for tourists. This has apparently affected the hourly distribution of fishing effort, forming a fishing pattern different from those seen in most fisheries. A knowledge of the hourly distribution of fishing is often important in creel census programs where sampling is done for less than the entire fishing day.

Good opportunity is afforded at Yellowstone Lake for the study of the effects of changes in regulations. This is due in part to the excellent cooperation received from the National Park Service and the Yellowstone Park Company in the collection of data. Also, there was a good opportunity for rather complete creel census coverage due to the existence of good sampling locations on the lake and river and to the good control of tourists at park gates, on roads, and on the lake.

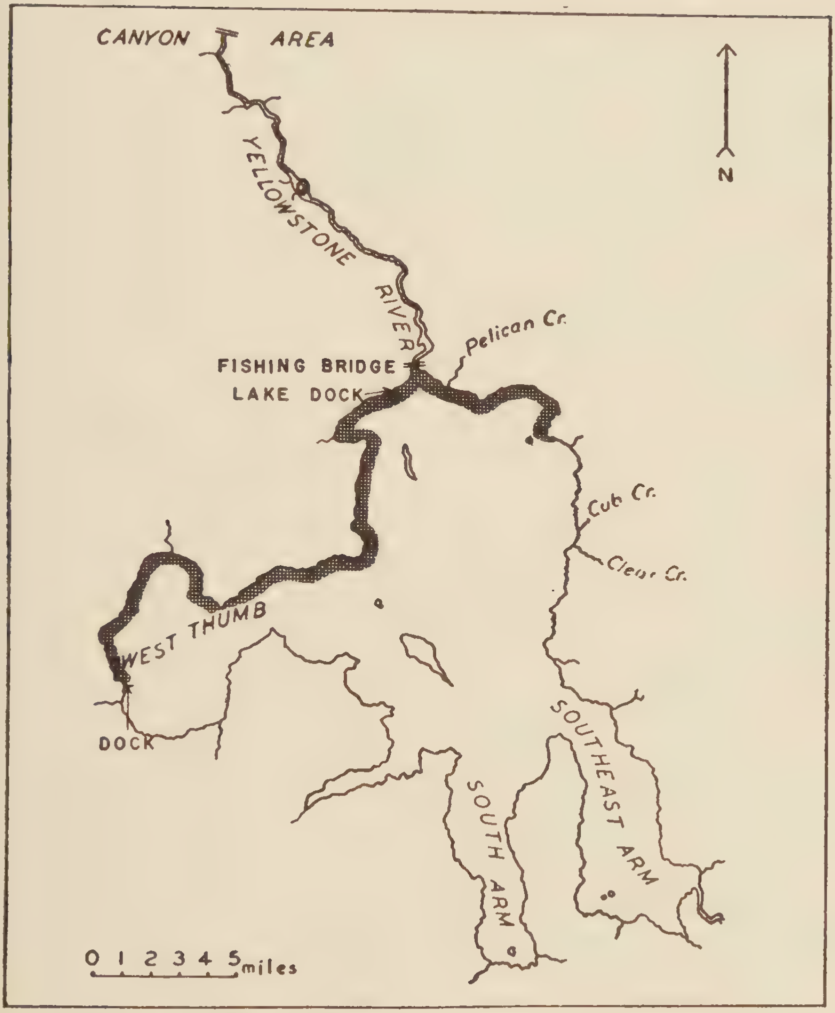


FIGURE 1.—Map of Yellowstone Lake and part of the Lower Yellowstone River, showing boat docks and other fishing landmarks. The shaded portion denotes the area involved in the shoreline fishery.

METHODS

Simple ratio estimates involving the application of sampling results to total numbers of anglers have been used to determine the total catch and the total effort for most elements of the fishery in all 6 years. Detailed data have been provided by the Yellowstone Park Company on numbers of fishermen and numbers of boats rented at Fishing Bridge, Lake, and West Thumb. These data were supplemented by other information secured by sampling. The U. S. National Park Service furnished data on total boat permits issued for private trailer boats. The census method used for Yellowstone Lake shoreline and for Yellowstone River features the complete-incomplete census system described in the earlier paper.

There have been a few departures from the census methods used in 1951. The 1950–1951 method featured interviews at each boat dock, four times every two weeks. One innovation made in 1952 involved the use of a semi-volunteer census card system to replace the interview system. The objectives of the card system were to conserve manpower and increase the sample size. Questionnaire cards, shown in Figure 2, were handed to the fisherman when they paid their bills, and the boat dock cashier entered the fishing time on each card.

The card system was not adopted until the method had been tested at Fishing Bridge Dock. From May 30 through June 26, the interview and card censuses were conducted and a statistical comparison of the two methods was made (Table 1). There was no statistically significant difference between the two methods, so the semi-voluntary card system was adopted forthwith at both Fishing Bridge Dock and West Thumb Dock.

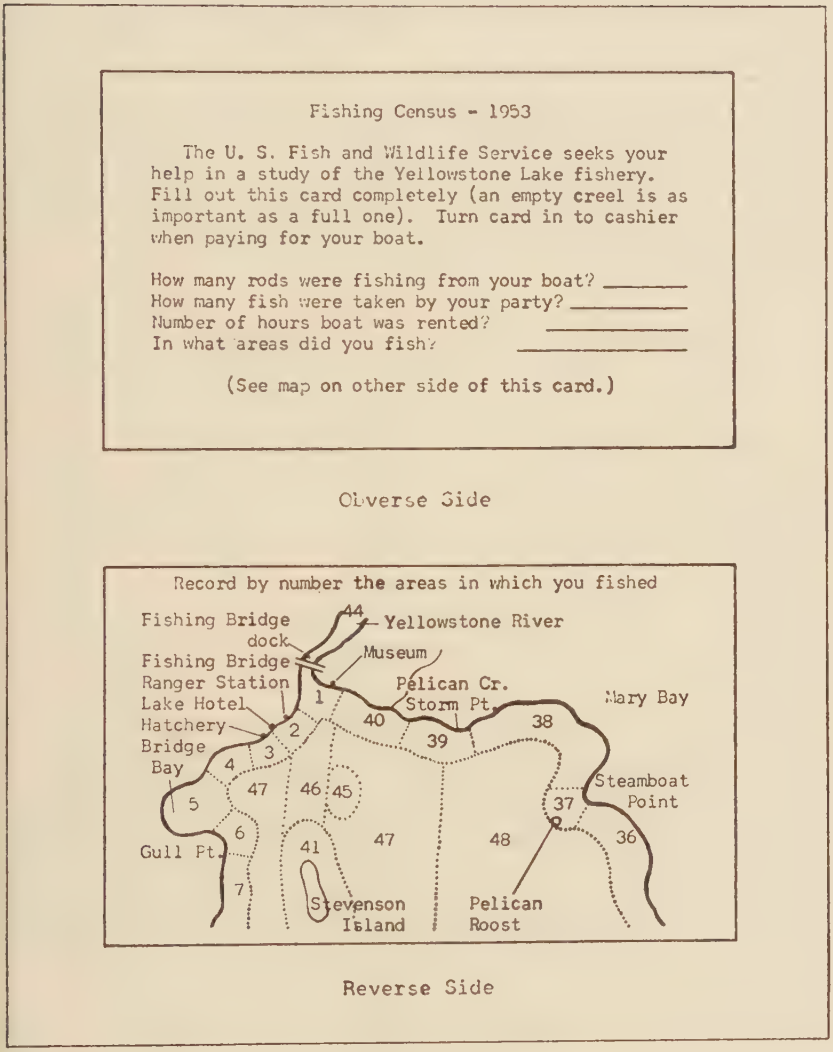
The shoreline census consisted of the incomplete census (touring the shoreline and counting fishermen) and the complete census (tabulating individual efforts and catches in one area throughout the entire fishing day). The frequency of incomplete censuses was increased from four to six per sampling period after 1951, and complete censuses were increased to six in each two-week period after 1952.

An important improvement in the Yellowstone River estimates was made by interviewing anglers after the fishing day was completed to determine average fishing time. Formerly the anglers had been interrogated before their fishing was terminated. The 1951 estimates have been revised in the light of this information.

One point should be mentioned in connection with time periods for 1952. The opening day for fishing on Yellowstone Lake in the first 3 years of investigation was May 30; the opening day in 1953–1955 was June 15. The second period of former years which began on June 13 is compared with the first period in 1953 although there is a 2 day discrepancy.

HOURLY DISTRIBUTION OF EFFORT

Yellowstone Park is a resort area whose visitors usually stay in the park for several days during a visit. Many tourists move constantly during their stay in Yellowstone, but the great majority remain at resort centers such as Mammoth or Old Faithful for at least a few days before moving on. Tourists who camp in tents or trailers usually stay for several days to a month in one locality. The area bordering the lakeshore from West Thumb to the Fishing Bridge area is replete with living facilities for the semi-permanent, as well as the temporary Yellowstone visitors.



Fishing Census - 1953

The U. S. Fish and Wildlife Service seeks your help in a study of the Yellowstone Lake fishery. Fill out this card completely (an empty creel is as important as a full one). Turn card in to cashier when paying for your boat.

How many rods were fishing from your boat? ________

How many fish were taken by your party? ________

Number of hours boat was rented? ________

In what areas did you fish? ________

(See map on other side of this card.)

Obverse Side

Record by number the areas in which you fished

Reverse Side

FIGURE 2.—Fishing census cards used for the rowboat fishery. The cards were filled out after the fishing had been completed.

This resort situation has a controlling influence upon the hourly and daily fishing pattern on Yellowstone Lake and River. Hours of fishing on Yellowstone Lake and River are limited by National Park Service regulations to the time between sunrise and dark. Sunrise is from 4:30 a.m. to 5:50 a.m. during the fishing season and nightfall occurs from 7 p.m. to

9 p.m. Anglers do not fish early in the morning but ordinarily appear between 7 and 8 a.m. However, a few anglers begin their fishing at the crack of dawn at Fishing Bridge. Private boats often remain at fishing sites until dark. The census was adjusted to the habits of the fishermen.

The distribution of fishing effort throughout the day is somewhat unusual on Yellowstone Lake. Most fisheries adhere to a bimodal distribution of effort such as that reported by Eschmeyer (1935) on Fife Lake, where there was a morning peak from 8 to 10 a.m. and an evening peak from 6 to 7 p.m. Smith (1950) reported a similar pattern on the Sacramento River in California, with peaks at 9 a.m. and 4 p.m.

TABLE 1.—*Comparison of results of two methods of estimating fishing success. Fishing Bridge Dock, May 30 — June 26, 1952*

Date	Catch per hour		Number degrees of freedom	*t* value
	Interview estimate	Card estimate		
May 30	0.2315	0.3597	88	1.179
June 3	1.1019	0.7490	43	1.057
do. 6	0.6530	0.8643	53	1.023
do. 7	0.3124	0.4598	92	1.372
do. 9	1.0681	0.9628	54	0.282
do. 13	0.5471	0.5314	50	0.008
do. 17	0.7820	1.3538	11	0.844
do. 20	0.9209	0.9407	58	0.078
do. 23	1.1466	0.7655	59	1.383

The daily distribution of fishing effort on Yellowstone Lake and Yellowstone River has been computed from angling hours measured throughout the complete seasons of 1952 and 1953. The 1952 patterns are shown in Figure 3. A definite trimodal pattern of distribution occurred for the lake and river in both years. Each curve shows fishing effort to be very low in the morning from 7 to 8 a.m., reaching a rapid, high peak in late forenoon, another lesser peak in the late afternoon, and a third one in the early evening. The morning and afternoon peaks were an hour earlier in 1953 than in 1952, but the evening peak occurred from 6 to 7 p.m. in both years.

DAILY DISTRIBUTION OF EFFORT

Most sport fisheries are patronized far more heavily on weekends and holidays than on week days, a condition that has significance in the sampling schedule of the creel census. Smith's (1950) data showing effort and catch for the Sacramento River fishery from May, 1948 to February, 1950 are typical of the usual fishery. The average number of fishermen per day contacted and seen on Sundays and holidays was 64.3, on Saturdays, 49.1, and 25.2 on week days. Another example of great differences in fishing effort on Bear Lake, Idaho between week days and weekends of 1953 is provided by Mr. William McConnell, fishery biolo-

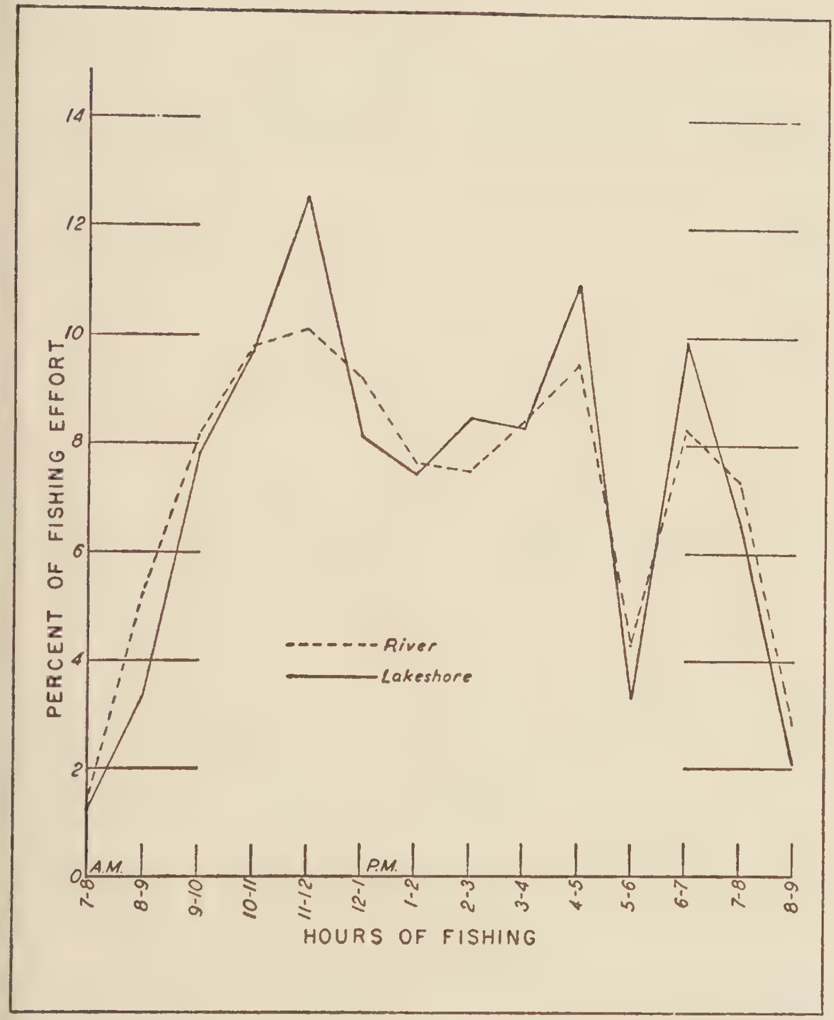


FIGURE 3.—Distribution of fishing effort by hours of the fishing day, for lakeshore and river, 1952.

gist of the Utah Department of Fish and Game, and Mr. William Clark, fishery biologist of the State of Idaho. The average number of anglers counted on Saturdays, Sundays, and summer holidays was 24.96 per day, and the average number of anglers per week day was 7.16.

The distribution of fishing effort on Yellowstone Lake follows a different pattern and again reflects the "resort" situation (Fig. 4). Rowboat and guideboat rentals at the various docks in 1953 were segregated according

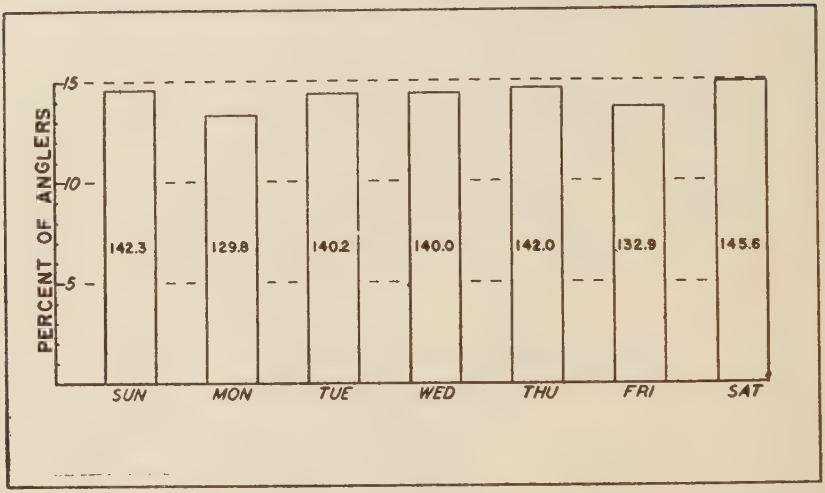


FIGURE 4.—Distribution of fishing effort, by days of the week, computed from numbers of fishermen using rowboats and guideboats from Fishing Bridge, Lake, and West Thumb docks in 1953. The figures in the bars represent average numbers of fishermen per day.

to days of the week for the entire season. These units were chosen as an illustration because of the completeness of the data. There was a strikingly uniform fishing pressure from day to day compared with the Bear Lake and Sacramento River fisheries. The day of greatest average fishing pressure at Yellowstone was Saturday and the lowest average pressure was on Monday. Weekend anglers from Cody, Wyoming, Idaho Falls, Idaho, and Livingston, Montana, do enter the park for Saturday and Sunday fishing, but in such small numbers that they may not significantly increase weekend fishing pressure. Their relatively high efficiency as anglers, however, probably considerably increases the total catch.

Sampling of the various units of the Yellowstone Lake and River fishery is relatively simple since all days can be treated alike. Weather remains as the largest single influence on fishing intensity from hour to hour and from day to day.

DISTRIBUTION OF EFFORT ACCORDING TO AREA AND SEASON

Some areas of the Yellowstone fishery exhibit constant patterns year after year, and knowledge of these patterns has value in the management of the fishery. An example of this tendency is found in 4 years' rowboat catch data from Fishing Bridge fishery area and West Thumb fishery area (Fig. 4). The catch in the Fishing Bridge area quickly builds up to a peak at the end of June and immediately begins a decline which persists to the end of the season. The West Thumb fishery, in contrast, increases slowly from the beginning of the season until the middle of August, at which time a sharp decline begins. The West Thumb fishery, then, is relatively small but sustained, while the Fishing Bridge area fishery peaks rapidly and declines quickly. The Fishing Bridge area fishery is of greater magnitude than is the West Thumb fishery, throughout the entire season.

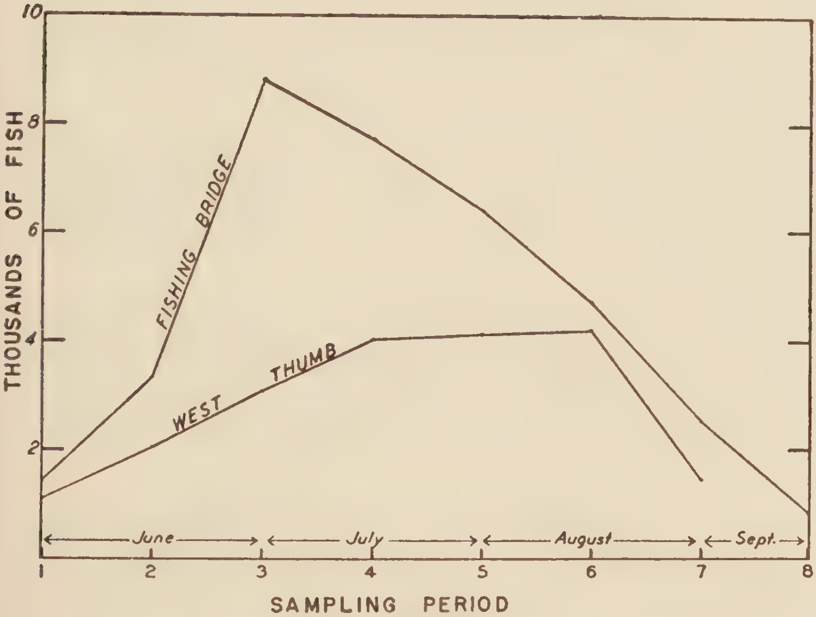


FIGURE 5.—Catch, in thousands of fish, plotted against sampling periods throughout the season, for the Fishing Bridge fishing area and the West Thumb fishing area. Catch figures are based on rowboat landings, and are mean annual catches for the years 1950–1953.

These curves can be explained on the origin of the fish entering the fisheries. The Fishing Bridge area fishery is strongly influenced by spawning migrations to Fishing Bridge, Pelican Creek, Clear Creek and Cub Creek. The height of the migration of spawners coincides with the peak catch in the Fishing Bridge area. On the other hand, the West Thumb fishery is not influenced by spawning migrations, since there are no streams supporting large runs in this area. A large portion of the fish taken in the West Thumb fishery enter the area after having spawned in other places, an observation supported by tagging studies. The delays encountered in getting back to the lake after spawning and in moving northward account for the sustained harvest in the West Thumb fishery.

CENSUS RESULTS

Fishing Bridge Dock.—Fishing Bridge Dock occupies an important place in the fishery scheme on Yellowstone Lake. It is located 50 yards downstream from Fishing Bridge and a half mile downstream from the outlet of Yellowstone Lake. The dock is situated so that fishermen can utilize the lake, the intermediate area between lake and river, and the upper end of the Yellowstone River proper. This dock rents more rowboats than does either Lake Dock or West Thumb Dock, and more fish are landed here than elsewhere. Lake Dock, located a mile west of Fishing Bridge Dock, specializes in guide boat fishing, has some rowboat rentals, and also caters to private boats.

The most noticeable features of the rowboat data are the high catch-per-hour value for 1952 and the low fishing effort for 1953–1955 (Table 2). The reduced effort of 1953 was undoubtedly related to the lowered limit, the shortened season, and poor weather in June. Travel to the park was only 1.7 percent lower than in 1952, while fishing effort on Yellowstone Lake was 27.2 percent lower.

The guideboat fishery from Fishing Bridge Dock was eliminated after 1953. Different annual rates of fishing success resulted in total catches in this fishery varying from 19,000 to 26,000 fish from 1950 to 1953. The general trend in fishing success in this element of the fishery was downward, and suggests a decrease in the availability of fish to guide boat anglers. The average hours fished, per fisherman, decreased from 2.20 hours in 1950 to 1.84 hours in 1953.

A noteworthy difference in fishing success between rowboats and guideboats appeared each year. The highest catch-per-hour measurement for rowboats at Fishing Bridge Dock was 0.735 in 1952, while the lowest recorded for the guideboats was 1.441 in 1953. The advantage in favor of guideboats can be attributed to the skill of the fishing guides and to the ability of guide boats to penetrate to good fishing areas not accessible to the smaller rowboats.

West Thumb Dock.—The rowboat fishery of West Thumb Dock fluctuated moderately in effort from 1950 to 1955 (Table 3). The catch-per-hour was fairly uniform with only a slight reduction in 1952. Fluctuations in total catch were mainly functions of effort expended, except in 1952. Rowboat fishing success at West Thumb was about the same as at Fishing Bridge Dock, although the angling effort was considerably lower at the former location.

Guide boats at West Thumb underwent a decline from 1.785 to 1.120 in catch-per-hour from 1950 to 1953, but rose to 2.280 by 1955. Effort and catch were considerably less than at Fishing Bridge, but success was only slightly lower. Guide boats had a fishing success more than twice as great as that for rowboats, as at Fishing Bridge.

Lake Dock.—Fishing activity at Lake Dock was emphasized by the concessionnaire in 1954 and 1955. Guide boats at this location replaced those at Fishing Bridge Dock, and rowboat rentals increased. Results

TABLE 2.—*Creel census results, Fishing Bridge Dock, 1950—1955*

Year	Sampling results					Yellowstone Park Company records		Estimates	
	Number of fishing parties	Number of fishermen	Number of fishermen hours	Catch	Average catch per man hour	Number of fishing parties	Number of fishermen	Total fisherman hours	Total catch
Rowboats									
1950	3,633	8,202	21,716.3	11,456	0.528	10,330	25,727	68,177	35,997
1951	2,031	4,847	14,112.6	6,513	0.462	9,162	27,578	80,252	37,076
1952	1,436	3,498	11,215.7	8,243	0.735	7,293	21,587	69,294	50,931
1953	1,436	3,547	9,541.4	4,608	0.483	6,900	17,642	47,509	22,938
1954	2,341	5,985	15,005.8	7,698	0.513	5,906	15,102	41,804	21,461
1955	3,398	8,073	24,340.5	11,294	0.464	7,204	17,117	49,440	22,920
Guideboats[1]									
1950	602	1,934	4,254.0	8,482	1.993	1,422	5,016	11,035.2	21,960
1951	1.102	3,679	7,484.3	16,287	2.176	1,620	5,882	11,940.5	26,029
1952	576	2,014	5,292.7	8,361	1.580	1,614	5,389	14,173.1	22,393
1953	638	2,308	4,256.0	6,134	1.441	1,978	7,177	13,203.4	19,025

[1] Guideboats not fished from Fishing Bridge Dock in 1954 or 1955

TABLE 3.—*Creel census results, West Thumb Dock, 1950—1955*

Year	Sampling results					Yellowstone Park Company records		Estimates	
	Number of fishing parties	Number of fishermen	Number of fishermen hours	Catch	Average catch per man hour	Number of fishing parties	Number of fishermen	Total fisherman hours	Total catch
				Rowboats					
1950	1,316	3,222	9,911.2	5,234	0.528	4,692	11,761	36,224	19,126
1951	952	2,336	6,654.0	3,971	0.597	4,769	14,057	40,062	23,917
1952	2,106	5,146	20,295.9	8,798	0.434	4,595	13,936	54,908	23,830
1953	558	1,306	3,679.0	1,953	0.531	4,115	10,574	29,819	15,834
1954	2,185	5,418	16,025.1	7,644	0.477	4,565	11,321	32,864	15,678
1955	669	1,696	5,024.3	2,797	0.566	4,892	12,400	36,755	20,817
				Guideboats					
1950	171	581	1,350.7	2,411	1.785	470	1,507	3,511	6,268
1951	63	218	507.6	664	1.307	311	1,123	2,617	3,420
1952	137	494	1,299.2	2,054	1.581	353	1,216	3,198	5,056
1953	290	1,126	2,494.0	2,794	1.120	515	1,845	4,078	4,567
1954	215	628	892.9	1,751	1.961	436	1,272	1,850	3,627
1955	104	417	547.4	1,248	2.280	875	3,500	4,630	10,562

measured at Lake Dock were: Guideboats, 1954, 17,155 hours of effort, and a catch of 28,773 fish; 1955, 21,713 hours of effort, and a catch of 30,922 fish. Rowboats, 1954, 4,456 hours of effort, and a catch of 2,830; 1955, 5,748 hours of effort and a catch of 4,249.

Fishing Bridge.—The yearly catches generally reflect the amount of fishing effort at Fishing Bridge (Table 4). Catch-per-hour showed a downward trend from 1950 to 1953, but increased in 1954–1955. In all years, catches from Fishing Bridge were closely associated with spawning migrations in Yellowstone Lake and River. Consequently, the fishery has been most successful for about three weeks following the July 1 opening date.

TABLE 4.—*Creel census results, Fishing Bridge, 1950—1955*

Sampling results				Estimate	
Year	Rod hours	Catch	Catch per rod hour	Total rod hours	Total catch
1950.........	3,408	556	0.163	39,372	6,417
1951.........	10,395	1,647	0.158	41,613	6,575
1952.........	9,103	1,258	0.138	35,256	4,865
1953.........	11,580	1,504	0.130	41,448	5,388
1954.........	13,484	2,225	0.165	42,744	7,072
1955.........	10,506	1,760	0.168	36,771	6,165

Lakeshore.—The census on the lakeshore was conducted in accordance with the methods described in the earlier report. In the cases of the second and third periods of 1952, an irregularity in sampling resulted in estimates that were obviously too high. Revised catch and effort estimates were therefore substituted for these values, and appear in Table 5. The results of this census show fair agreement in success from year to year. The catch of 1955 was the largest, but angling success was highest in 1950. Calculations of standard deviation appear in Table 5. The census shows increases in the amount of fishing and the catch-per-unit-effort data suggest no diminution in the population available to the fishery.

TABLE 5.—*Creel census results, Yellowstone Lake shoreline, 1950—1955*

Year	Number of fishermen	Number of fisherman hours	Standard deviation	Number of fish	Standard deviation	Catch per fisherman hour
1950.........	50,260	85,281	[1]	55,370	[1]	0.649
1951.........	114,743	120,651	±6,387.0	48,965	±8,474.4	0.406
1952.........	110,997	132,113	[2]±3,653.1	53,423	[2]±3,287.0	0.404
1953.........	82,447	112,914	±3,521.6	64,116	±2,572.3	0.522
1954.........	71,068	116,804	±2,286.3	71,919	±1,967.2	0.616
1955.........	87,156	175,149	±3,784.5	97,831	±2,967.7	0.559

[1] No standard deviation estimated because of census method

[2] Estimates derived by other than the usual method

Trailer boat fishery.—The volunteer boat card method described in the former report was also used successfully in 1952–1955. The cards were issued to private boats as they entered the park, the fishermen recorded information on catch and effort, and the cards were returned at the park gates when the boats left the park. More than 25 percent of the cards issued in each year were returned. The greatest use of small, trailer-type boats was made in 1955, with 2,691 boat trips on Yellowstone Lake carrying 9,284 fishermen. This important part of the Yellowstone Lake fishery has shown a steady decline in fishing success over the 6–year period (Table 6).

Cruiser fishery.—The number of large private boats (20 to 30 feet) used for fishing on Yellowstone Lake has increased from year to year, and in 1954 nearly reached the maximum dock and anchorage capacity on the lake. The cruiser catch is the poorest known unit of the Yellowstone fishery because of the unwillingness of many boat operators to keep catch records. It was necessary to base estimates on records for only a few boats for 1950. The 1953–1955 catch estimates are based on the time each boat was used on the lake, the number of passengers in each boat, and the assumption that limit catches were made by nearly each person each day. The 1953 catch for cruisers on Yellowstone Lake greatly surpassed those for previous years, but the 1954 and 1955 catches were a little lower. It was not feasible to compare year-to-year fishing success in this element of the fishery. Cruiser catch estimates are shown in Table 7.

Yellowstone River.—The method for censusing the Yellowstone River after 1951 featured a modification of the lakeshore method. The 1951 values were adjusted in accordance with the average fishing time per person measured in 1952 and 1953 (Table 8). The numbers of fishermen on the river increased up to 1953 and then decreased, but effort did not change in proportion. Catch-per-hour was 0.649 in 1955, which surpassed all previous years.

The Lake Outlet.—Yellowstone Lake and Yellowstone River meet in a boundary area which seems to be ecologically different from either lake or river. The boundary is defined as the region between Fishing Bridge and 300 yards downstream. It is fished by rental and private boats and fishermen angling from the bridge. The area supports more fishing pressure and a greater catch than any other place on the lake or river of comparable size. The average annual hours of fishing for Yellowstone Lake and River are 454,703 hours (cruisers excepted), and the boundary area fishing was 150,042 or 33 percent of the lake and river combined. With respect to catch, the average annual harvest of Yellowstone Lake and River was 288,519 fish and the boundary area harvest was 75,009 fish, or 26 percent.

Yellowstone Lake and River offer about 50 miles of shore fishing and over 100 square miles of water for boat fishing. Yet, 33 percent of the fishing effort and 26 percent of the catch were concentrated at the boundary area. The area adjacent to Fishing Bridge is thus regarded as the most important fishing area of its size in the drainage. It should be

TABLE 6.—*Creel census results, trailer boat card census, 1950—1955*

Year	Average days on lake	Average anglers in boat	Average catch per boat day	Number boat trips on lake[1]	Number of fishermen	Efforts (hours)	Catch estimate	Catch per hour
1950...........	[2]2.85	[2]3.24	[2]12	1,473	4,773	49,389	50,377	1.020
1951...........	2.85	3.24	12	1,604	5,197	55,954	54,857	0.980
1952...........	2.94	3.28	10.18	2,619	8,590	94,047	75,457	0.802
1953...........	3.35	3.23	7.39	1,979	6,392	73,713	50,118	0.680
1954...........	3.41	3.40	8.21	1,831	6,225	75,327	51,222	0.680
1955...........	3.58	3.45	8.33	2,691	9,284	115,000	80,270	0.698

[1] Including re-entry trips
[2] Rates assumed to be the same as for 1951

considered as an intermediate zone, apart from Yellowstone Lake and from the rest of Yellowstone River. This area supports a tremendous spawning concentration from both the lake and river and the anglers take advantage of these unusual concentrations of fish.

TABLE 7.—*Creel census results, cruiser type boats at West Thumb, Lake and Fishing Bridge Docks, 1950—1955*

Year	Number of boats	Estimated number of trips	Catch estimate
1950	15	.....	4,500
1951	11	.....	5,052
1952	23	.....	9,322
1953	64	1,257	13,887
1954	89	1,557	13,351
1955	87	1,508	12,320

TABLE 8.—*Creel census results, Yellowstone River, 1951—1955*

Year	Number of fishermen	Fisherman hours	Standard deviation	Catch	Standard deviation	Catch per hour
1951	[1]26,713	83,614	±3,527.9	19,729	±3,388.6	0.236
1952	31,694	91,437	±2,802.6	20,603	±3,363.9	0.225
1953	59,395	80,664	±2,163.4	27,932	±2,258.1	0.346
1954	39,684	75,134	±1,533.5	35,912	±1,517.9	0.478
1955	49,087	75,692	±2,243.6	63,701	±5,764.3	0.649

[1] Adjusted from figures formerly published

TRENDS IN THE FISHERY

Postwar travel to Yellowstone increased each year up to 1952, except for a small decline in 1950. The 1953 count of tourists was slightly below the travel peak attained in 1952, but increases ocurred in 1954 and 1955. The trends in travel were reflected in the amount of fishing on Yellowstone Lake and River; measurements of hours of fishing pressure showed a peak in 1952, followed by a decrease in 1953 and increases in 1954 and 1955.

Numbers of tourists to Yellowstone were 1,109,926 in 1950, 1,166,346 in 1951, 1,330,387 in 1952, 1,326,858 in 1953, 1,328,893 in 1954, and 1,368,515 in 1955. Changes in fishing pressure followed those for tourist pressure at Yellowstone, with the following total numbers of angling hours computed for Yellowstone Lake: 292,989 in 1950, 353,090 in 1951, 402,989 in 1952, 332,684 in 1953, 333,004 in 1954, and 445,206 in 1955. Total catch figures for Yellowstone Lake were: 200,015 in 1950, 208,255 in 1951, 245,277 in 1952, 195,873 in 1953, 215,933 in 1954, and 286,056 in 1955, showing that catch totals were roughly proportional to those for travel to the park. The exception to this relationship was in 1953, when restrictions were placed on the fishery and a decrease in effort and catch resulted.

The elements of the fishery subjected to the greatest fishing pressure from year to year were the Fishing Bridge rowboats, private trailer boats, and the lake shoreline, although not always in that order. The portions of the fishery enjoying the greatest fishing success were the West Thumb, Lake and Fishing Bridge guide boats and the private trailer boats. It is judged that private cruisers had a fishing success similar to that for guide boats, although good measurements are not at hand.

The effects of changed regulations in 1953 were twofold: the shortened season and three-fish limit had a direct effect by reducing total seasonal fishing effort, and an indirect influence through a reduction in numbers of fishermen attracted to Yellowstone. The three fish limit definitely did not attract fishermen from nearby states to the extent that the former larger limits had done. These factors caused a 20 percent decrease in angling pressure in 1953, even though the West Thumb guide boats and Fishing Bridge increased in total hours of fishing. The catch was likewise decreased, but to a lesser degree than the effort. Figure 6 shows the relationship between travel to Yellowstone and fishing pressure on

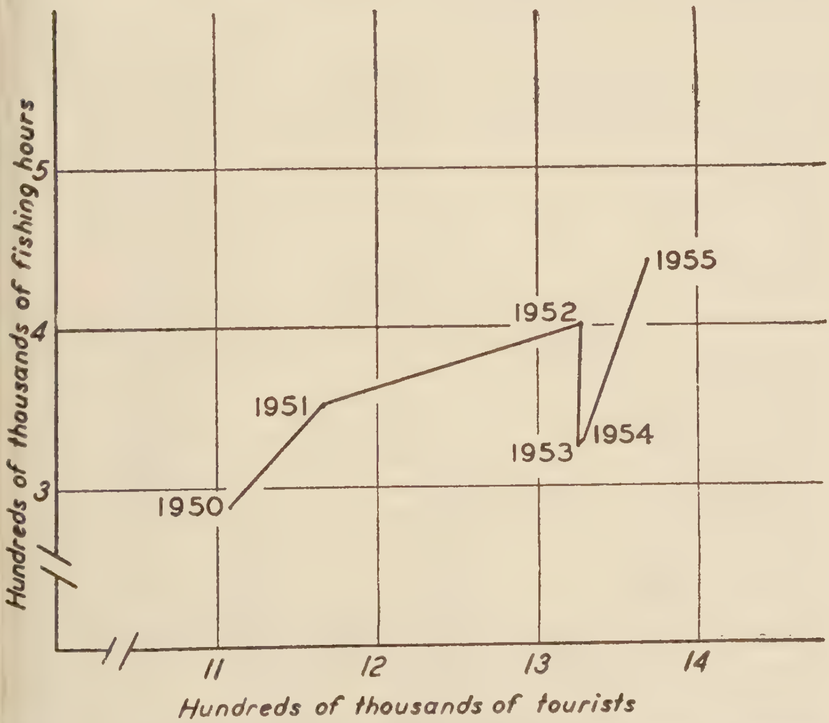


Figure 6.—Fishing effort plotted against numbers of tourists visiting Yellowstone Park, from 1950 to 1955. Fishing effort includes all elements of the fishery on Yellowstone Lake and Yellowstone River.

Yellowstone Lake, with fishing pressure increasing at a faster rate than travel from 1950 to 1951. The rate was reduced in the next year, and both travel and effort declined from 1952 to 1953. From 1953 to 1954 there was little change, but in 1955 fishing effort increased greatly in relation to increased travel. The shortened season would seem to be the most important factor in the decline of fishing effort.

The direct effects of reduced limits alone are important in the light of total catch. The distribution of limit and sub-limit catches for the years 1952 and 1953 are depicted in Figure 7.

In 1953, when the three fish limit was in effect, the percentages of limit catches were higher than in 1952, and there was no large reduction in total catch due to this regulation. Figure 7 shows that the combined values of 3, 4, and 5 fish catches in 1952 amount to about the same as the limit catches of 1953, and lower catches were similar in both years. So,

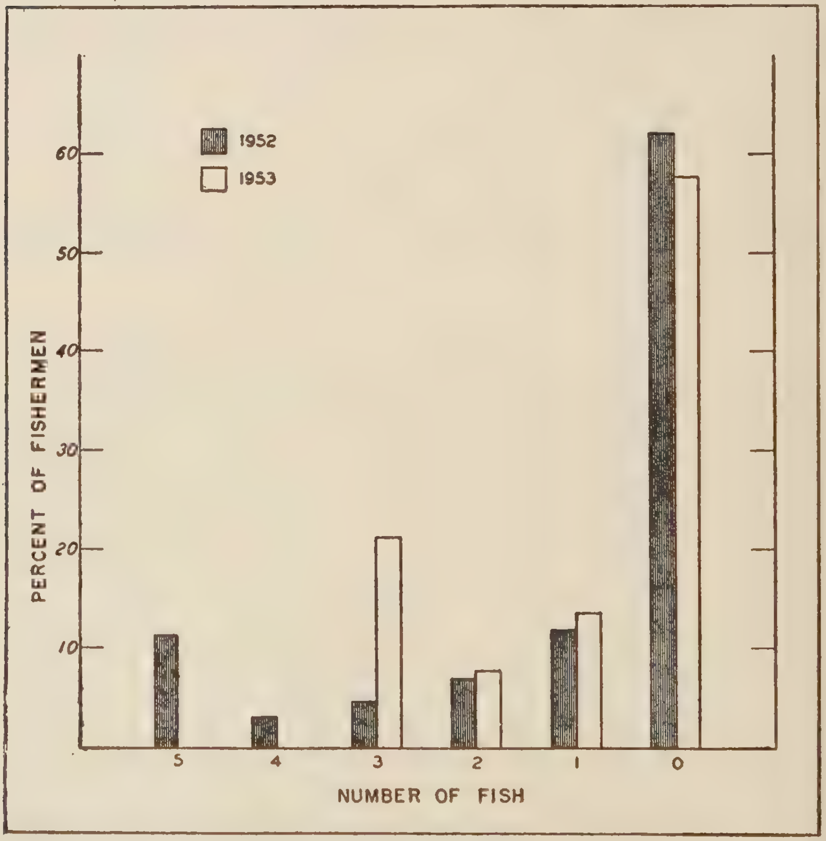


Figure 7.—Percentages of fishermen catching numbers of fish.

the lowering of the limit did not reduce the total catch in this case, but merely rearranged the distribution.

ANNUAL YIELD

Annual yield is commonly expressed in creel census studies in terms of the average number of pounds of fish harvested per acre of water. The Yellowstone Lake fishery does not lend itself to this kind of treatment, because of the uneven distribution of fishing pressure on the lake as indicated previously and because of the dependence of the fishery on concentrations of fish on spawning migrations. Some geographical units of the lake seem to harbor certain portions of the fish populations, according to the results of tagging, and they are treated individually.

The area of most concentrated effort and catch is the water from a point 300 yards below Fishing Bridge to a point a half mile above the bridge. This includes part of the lake proper. This area annually averaged 145.22 pounds of fish caught per acre for the years 1951, 1952, and 1953. The area served by the Fishing Bridge boat dock, comprising 6,555 acres and extending from a point 300 yards below Fishing Bridge to parts of the lake several miles from Fishing Bridge yielded 15.15 pounds per acre during these years. The West Thumb of Yellowstone Lake, with 11,345 acres, had an average annual yield of 3.37 pounds per acre. The whole of Yellowstone Lake, including the large central area, and the lightly-fished arms in the south part, yielded 1.75 pounds per acre annually for the three year period. It is apparent that none of the above figures is a true index of the productivity of Yellowstone Lake, but they can be used for comparative purposes.

SIZES OF FISH

Length measurements indicate that from 1950 to 1952 the lengths of fish landed in the Fishing Bridge area and the West Thumb area decreased significantly (Cope, 1953). Fish caught in the Fishing Bridge area in 1952 had a mean total length of 338.1 millimeters, a figure that is considerably higher than the West Thumb size of 323.6 millimeters. The 1953 collections were found to have larger fish than those of 1952. Fish from the Fishing Bridge area in 1953 had a mean total length of 360.8 millimeters, and the West Thumb samples averaged 331.8 millimeters. Relatively large mean lengths persisted in the fisheries of 1954 and 1955.

The increase in 1953 of average fish length is probably attributable to the recruitment of two weak year classes. The declines in mean length noted in 1951 and 1952 were due in a large part to the entrance into the late season fishery of numbers of small fish measuring 300 millimeters (11.8 inches) or less. There had been ample evidence of increasing numbers of these smaller fish in the fishery since 1948, especially toward the ends of the angling seasons, and their influence on mean lengths of the catch was great. The 1953 fishery landed fewer of this size group than did the fisheries of 1951 and 1953. Furthermore, a trap net fished near Fishing Bridge in 1952 and 1953 took less of these 12-inch fish in 1953 than in 1952. In 1952, 23.3 percent of the trap net catch consisted of fish 300 millimeters (11.8 inches) or less in length, while in 1953, only 6.2 percent of the catch were in this size group. This suggests that the fish of the 1950 and 1951 broods represent weak year classes, and accounts for the increase in mean length of the 1953 fishery.

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Many fishery biologists participated in these field studies and some have made contributions to the analysis and interpretation of results. Mr. Kenneth L. Liscom was active in the 1950 field program. Mr. Harvey L. Moore participated in the 1951 and 1952 field programs and performed analytical work on the data. Mr. Richard E. Beckwith designed the shoreline census method now in use, and advised on procedures and analysis. Mr. Martin Laakso supervised the field programs of 1953–1955. Mr. Orville P. Ball, Jr. of the Fish and Wildlife Service, and Dr. William F. Sigler, Department of Wildlife Management, Utah State Agricultural College, read the manuscript critically.

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e preservation of intact erythrocytes of marine vertebrates for blood group research.[1] J. E. Cushing, G. J. Ridgway and G. L. Durall.

The glycerol-freezing technique (*cf.* Chaplin *et al.,* 1954) appears to be a promising method preserving the erythrocytes of marine vertebrates collected in the field. The following points e as a guide for further study. Cells of several species of fish and one humpback whale have n treated. Whole blood from vessels in the gill, tail or other areas is allowed to run into ewcap bottles, as much as 25 to 50 ml. being taken. An equal volume of a solution containing cerol (40%) and 5% trisodium citrate (60%) is added and the mixture placed in a freezer proximately −20° C.) after thirty minutes.

Cells are recovered from a few ml. aliquots of thawed blood by reducing the glycerol con- of their milieu stepwise at five-minute intervals, using cool solutions. For example, albacore s were recovered by first adding an excess of 20% glycerol in 2% NaCl and then reducing glycerol, by dilution with 2% NaCl, to 14, 8.5, 6.5, 5.0, 4.0, 3.0, 2.0 and 1.5 per cents; 1.5% Cl was substituted and the glycerol reduced to 0.7, 0.35 and finally 0.0%. (Reasonable devia- s from this schedule were also successful.) The cells obtained kept well and could be used gglutination and absorption studies.

While the degree to which different antigens remain unchanged during prolonged storage bably varies, as in humans, cells of the whale, shiner seaperch, goosefish and three species of non retained antigenic specificities during preservation. Absorption experiments suggest in- dual differences in the antigens of preserved albacore cells that appear to resemble those of er tuna.

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Effects of Lake Fertilization by Volcanic Activity on Abundance of Salmon[1]

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ABSTRACT

Evidence from various sources—tree growth during the past century, chemical composition of waters of various lakes, plankton volumes, size of young salmon migrating seaward—tends to indicate that the fertilization of lake waters in western Alaska by volcanic ash during sporadic eruptions may be an important factor in determining the abundance of sockeye salmon.

This paper discusses the possible relation between volcanic activity and salmon production, especially of the sockeye or red salmon, *Oncorhynchus nerka.* The young sockeye usually remain in lakes until their second, third, or fourth year before migrating seaward to complete their growth, and thus the young of this species of salmon are most affected by any changes in the freshwater habitat, such as are wrought through volcanic activity.

Western Alaska (Fig. 1) has long been one of the richest fishing areas in the world; for amost fifty years the value of the annual salmon catch has averaged more than 30 million dollars by present-day standards. The abundance has been declining steadily, however, for several decades, until today in spite of fair numbers of spawners these fisheries are in critical condition. This area has also been noted for volcanic activity throughout historic time. That such activity was on a much larger scale prior to the advent of white men can be deduced from the profusion of volcanic cones almost everywhere—some dead, others somnolent but displaying occasional signs of life.

Alaskan volcanoes usually throw out pumice in the form of finely divided ash or porous rocks, rather than ejecting molten lava as do many volcanoes in other regions. The fine material is carried by the wind for varying distances (up to 300 miles in many cases) and laid down as a blanket of varying depth. This ash layer may be an important factor in salmon production.

VOLCANISM IN THE PENINSULA AREA

There is every reason to believe that most of the watersheds in this general area have received volcanic deposits, and in many instances so recently that a residual fertility probably remains. The most prominent of the volcanoes, starting at the southern end of the map (Fig. 1) are Mt. Veniaminof, Mt. Peulik, Mt. Katmai (including Novarupta), Mt. Trident, Mt. St. Augustine, Iliamna Volcano and Redoubt Volcano (this latter just off the map to the north).

Mount Veniaminof undoubtedly dropped large amounts of ash on the nearby lake system of the Chignik River when it erupted violently in 1892. Moving northeastward, the large Mt. Peulik volcano straddles the land bridge between Ugashik and Becharof Lakes, which must have received a large proportion of its ash. Next we come to the recently active Katmai volcanic area which we will discuss last.

The beautiful cone of Mt. St. Augustine on an island in the mouth of Cook Inlet erupted in 1883 and depending on the wind direction probably showered ash either on Iliamna Lake to the west or the watersheds of the Kenai Peninsula to the east.

The Naknek and Kvichak districts have a number of sporadically active volcanoes, some with craters so huge, e.g. Redoubt and Iliamna, that their outfalls could have made

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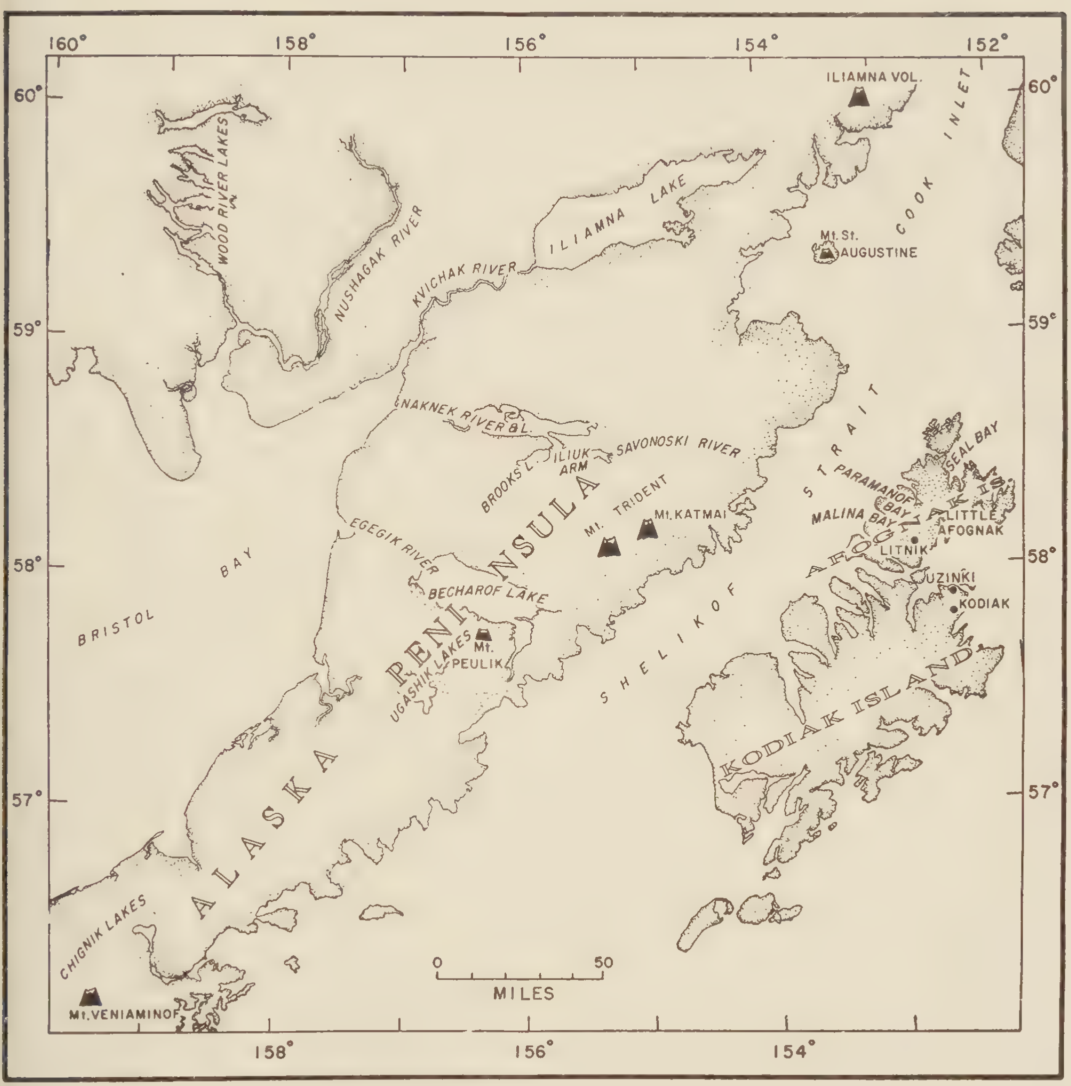

FIG. 1. Map of western Alaska showing location of places and volcanoes discussed in the text.

heavy deposits for at least a hundred miles in whatever direction the wind dictated.

Returning to the Katmai area, a great eruption occurred from June 6–12 in 1912 followed by a lighter eruption in September of 1913. Nearby Novarupta, a large but low volcano in an adjacent valley, threw out large quantities of ash and pumice at about the same time as the 1912 eruption of Mt. Katmai. Following a long period of dormancy Novarupta erupted violently for approximately two hours on May 19, 1949, a heavy outfall of ash being carried down Shelikof Strait by a westerly wind (observed by senior author). A few weeks later nearby Mt. Trident erupted, and it has exhibited sporadic activity almost to the present, although without significant ash outfall.

OBSERVED SHORT-TERM EFFECTS OF ASHFALL

Short-term effects of heavy ashfall on both fish and fish food organisms were observed during and following the heavy 1912 eruption of Mt. Katmai. Heavy clouds of ash were carried chiefly eastward by the wind prevailing at the time. According to Martin (1913) ashfall was between 10 and 20 inches in the area of Brooks Lake and Iliuk Arm of Naknek Lake but did not extend farther to the west. To the eastward the ash clouds were carried across Afognak and northern Kodiak Islands, the ash deposit reaching 10 inches at Kodiak and along Kupreanof Strait between the two islands.

Edward Ball (1914), inspector of Alaska salmon fisheries, stationed at Litnik on Afognak Island, gives a detailed account of the effect on salmon spawning and on fish food organisms. Since the eruption occurred before mid-June most of the salmon had not yet entered the streams, but these were suffocated by the turbid water and mud; approximately 4000 salmon died in Litnik Creek.

A survey of the principal stream systems on Afognak Island showed that in the eastern portion, where the ashfall was least, mollusks, worms, and some insect larvae could be collected. However, no crustaceans could be found. On the western side of the island the streams and lakes were almost destitute of fish food. The streams were so choked with sand and mud that about the middle of August several hundred salmon were suffocated in the same manner as just after the eruption.

During the following summer of 1913 attempts to collect seaward migrants (smolts) of sockeye salmon at Litnik Lake were made (Evermann 1914), but the number captured was so very meagre as to justify the conclusion that there had been a heavy loss of young salmon in the lake.

The question of the extent of this direct damage to the salmon runs and how quickly and how well the runs recovered can be at least partially answered by the records of the salmon fishery at three Afognak Island streams (Rich and Ball 1931). These give the annual catches by native fishermen for the canneries at Kodiak and Uzinki.

Data are available for most years from 1907 to 1921 (Table 1). Because the three streams are not of equal value as salmon producers, and because data are missing for some years prior to 1913, it has been necessary, in order to obtain the best estimate of relative abundance, to weight the catches for different streams. This weighting, based on the sum of the catches from 1913 to 1927 (except for 1916 when fishing in two of the streams was suspended), gives each stream equal weight and furthermore makes possible comparison of those years lacking data for one or two streams.

The average weighted catches and the trend smoothed once by a moving average of 3 are shown in Figure 2. The influence on survival of the heavy ashfall is very apparent in the small catches made from 1916 to 1920 when the returning adults would come from broods subjected to the ash while in fresh water. The young spend from 1 to 4 years (usually 2 to 3 growing seasons) in freshwater before descending to the sea. The majority of the adults are in their fifth year of life when they return from the sea on their spawning migration.

Thus the 1911 brood (run of 1916) would have just emerged from the spawning gravel at the time of the eruption in June 1912. The 1912 spawners were just commencing to ascend the streams. In 1913 the creeks were still ash-filled and a fresh eruption of smaller proportions occurred in September, 1913. The streams in 1914 were still very turbid following periods of rain.

The spawning runs from broods suffering major direct damage, especially the broods of 1911 to 1915 (returning as adults in 1916 to 1920), were small. However, the runs returning from the smaller numbers of spawners in 1916 to 1920 were fully as large as before the eruption.

The rapid recovery of these sockeye runs from the effects of the ashfall is of interest because when runs have been depleted by overfishing, lessening of the fishing intensity is seldom followed by such rapid recovery. This suggests very favorable environmental conditions, but whether these conditions were better food supply or perhaps a concomitant destruction of predators cannot be determined from the meagre data.

TABLE 1. *Sockeye salmon catches (in thousands of fish) for three streams on Afognak Island*

Year	Actual catches[1]			Catches weighted by factor			Average weighted catch	
	Seal Bay	Malina Bay	Paramanof Bay	Seal Bay	Malina Bay	Paramanof Bay	Average	Average smoothed by 3
1907	—	30	—	—	19.5	—	19.50	
08	16	7	—	24.5	4.6	—	14.55	23.53
09	21	63	—	32.1	41.0	—	36.55	26.37
1910	—	43	—	—	28.0	—	28.00	29.72
11	—	—	20	—	—	24.6	24.60	29.70
12	—	43	35	—	28.0	43.0	35.50	30.16
13	20	42	27	30.6	27.3	33.2	30.37	34.75
14	24	60	32	36.7	39.0	39.4	38.37	30.50
1915	18	42	11	27.5	27.3	13.5	22.77	27.28
16	7	(3)[2]	(2)[2]	10.7	—	—	10.70	14.99
17	7	12	13	10.7	7.8	16.0	11.50	12.61
18	7	14	22	10.7	9.1	27.1	15.63	15.35
19	12	23	19	18.4	15.0	23.4	18.93	16.82
1920	12	11	18	18.4	7.2	22.1	15.90	24.78
21	15	77	37	23.0	50.0	45.5	39.50	22.44
22	5	17	14	7.6	11.0	17.2	11.93	29.38
23	27	68	20	41.3	44.2	24.6	36.70	26.14
24	28	32	21	42.8	20.8	25.8	29.80	32.47
1925	27	28	27	41.3	18.2	33.2	30.90	33.24
26	20	101	17	30.6	65.6	20.9	39.03	26.77
27	8	12	9	12.2	7.8	11.1	10.37	
Sum 1913 to 1927 (Ex. 1916)	230	539	287					
Weight factor	1.53	0.65	1.23					

[1] Catches from Rich and Ball (1931).

[2] Fishing suspended after 3 weeks because of scarcity of fish.

FERTILIZATION OF WATERSHEDS BY ASHFALL

The evidence for significant fertilization of watersheds by ashfall and its long-term effect is based on plant and tree growth, on crude soil tests, and on the comparison of chemical content, plankton production, and smolt growth in lakes that received heavy ashfall from Katmai with lakes that did not.

Undoubtedly the chemical composition of the ash will vary in different eruptions and with distance and direction from the source. Griggs (1920) shows that the ash from the 1912 Katmai eruption included 0.36 per cent of phosphorus, 0.47 per cent of magnesium and 3.80 per cent of calcium. Phosphorus, especially, has been proved valuable in lake fertilization experiments. Unfortunately we have no phosphorus determinations for any of the lakes affected by the Katmai eruption.

The volcanic ash contains plant nutrients. At Kodiak where the ashfall averaged about ten inches, vegetation was greatly reduced during the first two years following the eruption due partially to smothering but perhaps also to overabundance of some chemicals and lack of humus. But Griggs (1920) found that after the second year, plant growth became so accelerated as to be far above normal.

The senior author has examined the growth history of five spruce trees, *Picea* sp., selected at random in 1951 from the forest near the shores of Brooks Lake, some 30 miles from Mt. Katmai. According to Martin (1913) this area received between 10 and 20 inches of ash deposit during the 1912 eruption, still clearly visible as a white pumice layer. Annual growth was determined by microscopic examination of radial cores removed from the trees with a

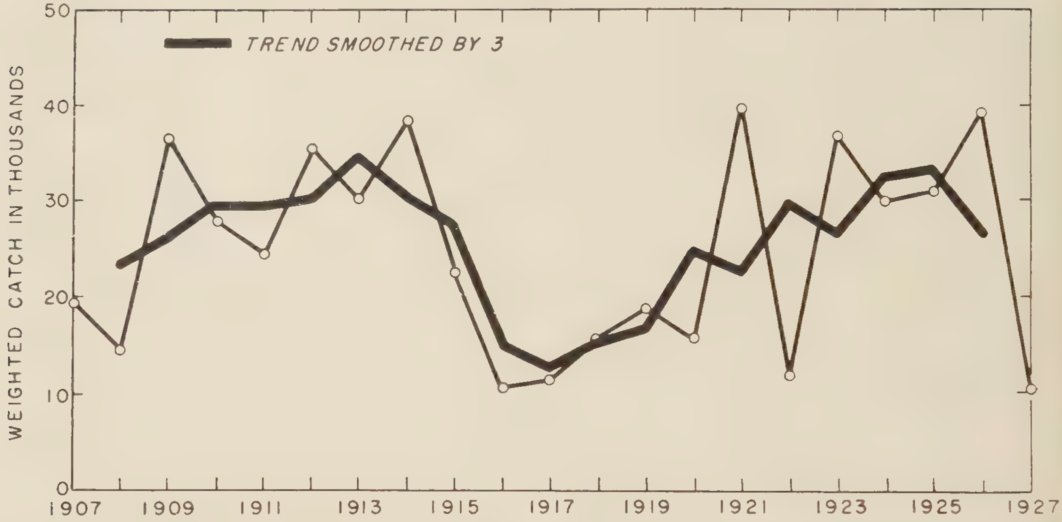

FIG. 2. Sockeye salmon catches from three areas on Afognak Island illustrating the short-term effect of the ashfall from the Katmai eruption of 1912 on salmon abundance.

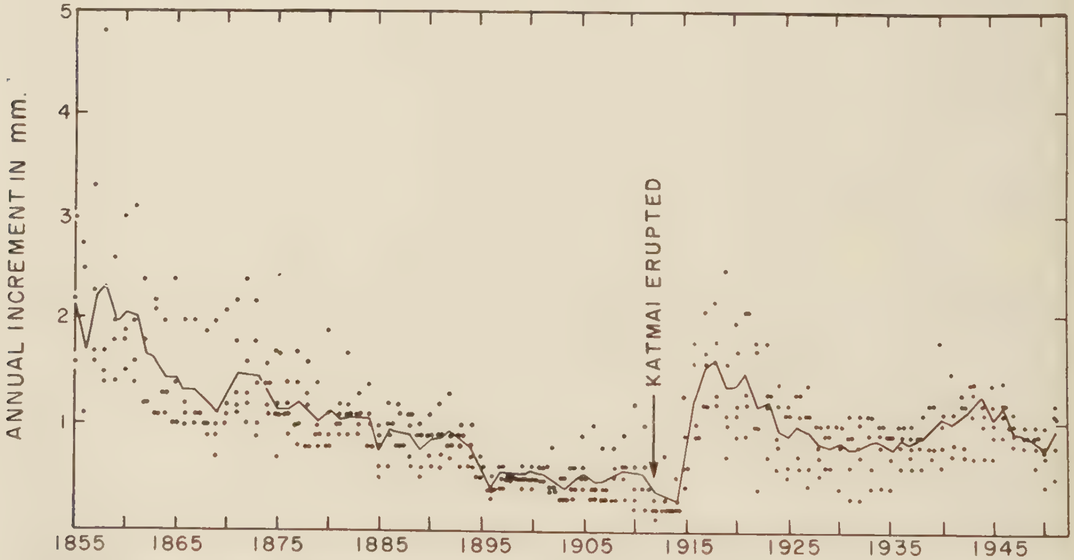

FIG. 3. Annual growth increments of five spruce trees from Brooks Lake, 1855 to 1951, illustrating the marked long-term effect of ashfall on soil fertility.

standard increment borer, utilizing a stage micrometer to measure the distance between adjacent growth rings.

Figure 3 shows the growth of these five trees from 1855 to 1951 when the cores were taken. The normal decline in growth rate with advancing age is clearly evident from 1855 until 1914, two years after the ash deposit from Katmai. After 1914 an abrupt and rapid upturn in growth occurred, reaching a peak in 1918. Growth has continued at a high level since that time. This parallels the observations of Griggs (1920) that two years of depressed growth preceded the accelerated growth of Kodiak vegetation after the eruption.

Enrichment of the soil by ash is corroborated by crude tests for nitrogen made by the senior author in 1947 at Brooks Lake. The top layer of soil, about an inch or less in depth, consisted largely of dead and partly-decayed vegetable matter showing a slight nitrogen content. Immediately below this the white pumice layer 6 to 15 inches thick from the Katmai eruption was high in nitrogen. Below this lay a black stratum of fine, sandy loam two or three feet deep showing no measurable nitrogen reaction. Gravel and sand extended downward from this point. A westerly wind prevailed at the time of the eruption so that on the Alaskan Peninsula (Martin *loc. cit.*) only Brooks Lake and Iliuk Arm of Naknek Lake received significant portions of the ashfall occurring between June 6 and 12 of 1912. Over the years a large proportion of the materials of value to fish have undoubtedly been slowly leached from the soils, and either have become adsorbed in the bottom sediments or been lost from the freshwater cycle by being flushed out of the lakes in the outlet streams.

Since algae, at the base of the aquatic food chain, can readily utilize inorganic nutrients, they would be expected to benefit from chemical enrichment of the soils of the watershed by ashfall, and this increase in basic food should be reflected in better growth rates of the young sockeye salmon which are pelagic in the lakes.

As mentioned above the young remain from one to four years in nursery lakes before dropping down to the sea for completion of their growth. The rates of survival of young red salmon in a lacustrine environment depend to a large extent on the rates of growth, since the faster they grow, the fewer are taken by predators. Ocean survival has also been shown by Kelez (1937), Barnaby (1944), and Foerster (1954) to depend to a large extent on the size of the fish when they reach the sea, the larger smolts having enhanced ocean survival.

Because available data bearing on this point (Table 2) were not originally collected with this analysis in mind they have some obvious deficiencies, yet they show some interesting features. The smolt samples from the Egegik system are too scant to be relied upon. For the other systems the largest smolts are from the Naknek River which includes smolts from both Brooks and the other lakes of the Naknek system. Comparison of Naknek-Brooks Lakes with Wood and Ugashik Lakes (Table 2) shows that smolt length appears to be definitely related to fertility. The possible long-term effects of volcanic enrichment are also indicated by the concentrations of chemicals after 35 years (1912–1947) in Brooks and Naknek Lakes, the only two in Bristol Bay benefitting from the Katmai outfall. In addition to the leaching of the soil in the usual manner, Naknek Lake still receives via the Savonoski River great torrents of pumice from the northern slopes of Mount Katmai. The chemical composition of this great volume of volcanic debris is a point

TABLE 2. *Limnological data and length of seaward-migrating sockeye smolts in Bristol Bay*[1]

River system	Sockeye seaward migrants in second year		Lakes sampled	Limnological data				
				Plankton volumes[2] cc/m³	Chemical analyses, ppm			
	Number	Length mm			Total hardness, as $CaCO_3$	Fixed carbon dioxide	Silica	Nitrite nitrogen × 10^{-3}
Kvichak			Iliama	—	18.8	15.0	1.2	1.0
Egegik	36	96.4	Becharof	2.0	26.6	22.4	0.2	1.0
Naknek	1837	101.9	Naknek	—	77.7	36.4	8.1	0.2
Do.			Brooks	20.0	37.2	32.7	9.1	6.0
Naknek summary		101.9		20.0	37–38	33–36	8–9	0.2–6.0
Ugashik	221	58.0	Ugashik	4.0	21.1	22.0	4.0	0.2
Wood	3074	60.1	Wood	12.5	20.3	11.2	3.2	1.0
Wood-Ugashik summary		58.0–60.1		4.0–12.5	20–21	11–22	3–4	0.2–1.0

[1] Smolt lengths in 1939, limnological data (surface) in 1947.

[2] Horizontal tows with standard Birge net.

deserving investigation, especially since lake fertilization is under study as a possible conservation measure.

The data available, although not sufficient to prove the beneficial effects of volcanic activity on the salmon runs, are highly suggestive. Study of the age, chemical composition, distribution, and thickness of ash layers in this area of Alaska, might aid in solving some of the questions concerning long-term trends in abundance of salmon.

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THE NEAR EXTINCTION OF LAKE TROUT IN LAKE MICHIGAN

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ABSTRACT

After the collapse of the commercial fishery for lake trout (*Salvelinus namaycush*) in Lake Michigan in the late 1940's, the further decline of the population was traced by records of numbers of small lake trout (mostly 11 to 16 inches in total length and 3 to 5 years old) caught in small-mesh nets of the chub (*Coregonus* [= *Leucichthys*] spp.) fishery. By 1951 the estimated abundance of these lake trout in lower Lake Michigan was only about 4 percent of their abundance prior to the invasion of the sea lamprey (*Petromyzon marinus*). This remnant of the population declined severely in subsequent years to a point near extinction by 1955. In April–July 1955 only 8 lake trout were caught in 5½ million linear feet of gill net.

Statistics of the lake trout and chub fisheries in State of Michigan waters of Lake Michigan for the years 1929–1954 give no indication that the destruction of small lake trout in the chub fishery had any effect on the later abundance of lake trout of commercial size, or that this destruction was a significant factor in the collapse of the lake trout fishery.

Lake trout were brought near extinction by lethal attacks of the sea lamprey and by the near or perhaps complete failure of natural reproduction in 1949 and subsequently.

Comparisons in 1949 and 1950 of numbers of legal-sized lake trout caught in large-mesh nets with numbers of small fish taken in chub nets showed that both large and small lake trout declined over the same period, and that by these years the decline may have been greater among small than among legal-sized fish.

INTRODUCTION

The decline of the commercial fishery for lake trout in Lake Michigan during the late 1940's was reported by Hile, Eschmeyer, and Lunger (1951). These authors demonstrated clearly that overfishing was not responsible for the decrease and held that the major cause of the catastrophe was the parasitic sea lamprey.

The decrease that led to a 95-percent drop in the annual commercial catch between 1944 and 1949 continued at an accelerated pace in the following years (Table 1). The take was reduced to only 3,500 pounds in 1952 and 34 pounds in 1955. The rate of decline in production was accentuated by a decrease in fishing intensity after lake trout abundance became so low that operations were unprofitable. Nevertheless, the change from an annual production of more than 6,000,000 pounds per year to one of less than 100 pounds within little more than a decade indicates a prodigious decrease in numbers of lake trout of legal size [2] in Lake Michigan.

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[1] Now associated with the Michigan Department of Conservation.

After commercial fishing for lake trout had practically ceased by the early 1950's, the only convenient source of information on the decline of the population was from records of the numbers of small lake trout captured in small-mesh (mostly 2½ inches, extension measure) gill nets of the chub fishery, a fishery which expanded tremendously after the collapse of lake trout production (Hile and Buettner, 1955). The present paper traces the 1951–1955 decline of this remnant of the lake trout population to a point near extinction.

TABLE 1.—*Commercial production of lake trout in Lake Michigan, 1944-55*[1]
[Thousands of pounds]

Year	Production	Year	Production
1944	6,498	1950	54
1945	5,437	1951	11
1946	3,974	1952	3
1947	2,425	1953	[2]..
1948	1,197	1954	[3]..
1949	342	1955	[4]..

[1] Data for 1944-1949 from Hile, Eschmeyer, and Lunger (1951)
[2] 402 pounds [3] 107 pounds [4] 34 pounds

MATERIALS AND METHODS

Materials for this study were obtained principally from reports of cooperating commercial fishermen in representative Lake Michigan ports, who maintained daily records of the number of lake trout caught in their chub nets in 1951–1955. In most of 1952 and in 1953–1955, the average depth at which each gang of nets was fished was also given. Data on the locality and the amount of gear fished were obtained either from the fisherman or from his monthly production reports to the conservation department of the state in which he operated. Records were collected by mail or in person at bi-monthly intervals, from June 1951 to December 1953 for all months during which nets were lifted, but in 1954 and 1955 the work was confined largely to the months April-July.[3] During periodic visits with operators, biologists accompanied boats to make supplemental observations. Agreement between observed and reported data proved the reliability of the fishermen's reports. Catch records were available for more than 55 million linear feet of net during the 5-year study; this gear was lifted by

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[2] Legal size is 1½ pounds in Illinois and Michigan waters and 17 inches, total length, in Wisconsin. For practical purposes the two limits may be considered equivalent. Since most measurements in this paper are in terms of length, "legal size" as used here indicates a total length of 17 inches.

[3] Data for earlier years as well as year-round records for fishing off Two Rivers, Wisconsin, in 1925–1930 (Van Oosten and Eschmeyer, 1956) demonstrated that April–July data would provide dependable estimates of changes in abundance of lake trout. The shorter index period seemed desirable in order to reduce the inconvenience to cooperating fishermen of maintaining the daily records.

13 fishermen situated at 11 ports in 4 states. Ports represented were: Manistique, Frankfort, Pentwater, Grand Haven, and St. Joseph, Michigan; Michigan City, Indiana; Waukegan, Illinois; and Racine, Port Washington, Sheboygan, and Sturgeon Bay, Wisconsin (Fig. 1). Most fishing was within 35 miles of the home port.

Records were compiled for each fisherman in terms of the average number of lake trout caught per 1,000 linear feet of gill net lifted from each 10-fathom depth interval in each month. Similar records for the experimental fishing of the research vessels *Fulmar* (1930–1932) and *Cisco* (1954–1955) provided contrasts between populations of small lake trout in Lake Michigan before and after the invasion of the sea lamprey.

ABUNDANCE OF SMALL LAKE TROUT IN LAKE MICHIGAN

Sources of variability in estimates of abundance.—The various factors influencing data on abundance of lake trout collected in small-mesh gill nets off different ports and in various regions of Lake Michigan were discussed in detail by Van Oosten and Eschmeyer (1956). They found differences in abundance of lake trout in three principal geographic regions of the lake—the east and the west shores of lower Lake Michigan, and northern Lake Michigan (north of a line from Frankfort, Michigan, to Algoma, Wisconsin). Such geographic differences persisted in 1951–1955; therefore, the data were separated according to the region of the lake in which they were collected.[4] Most geographic variations in abundance that occurred within these regions were not large. The one area that differed sharply from other parts of the same region of the lake (the Sheboygan Reef) has been treated separately. In most comparisons, records were compiled for each month of collection because the data showed rather strong and consistent seasonal trends in catch. The 1930–1932 records proved that depth of fishing had a marked effect on the number of lake trout caught. No appreciable difference was observed in bathymetric distribution of lake trout in 1952–1955, as compared to 1930–1932. Consequently some comparisons of catch per unit of effort were restricted to records of nets lifted from similar depths. Analysis of the 1952–1955 data revealed, however, that the range of depths fished by chub fishermen during the same months of different years were similar, and that the effect of variations in fishing depth on comparisons of abundance in successive years was relatively unimportant. It was accordingly possible to use with confidence the data for 1951 and early 1952, for which depth records were not available, in making estimates of annual changes in lake trout abundance.

Other factors that influenced the catch per unit of effort to an unknown degree were: the material from which nets were manufactured, mesh size and fishing time (nights out). These factors probably had little effect on comparisons among the years 1951–1955, when most nets were of 2½-

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[4] In the analysis of data for 1951–1955, data on fishing immediately north of the Frankfort-Algoma line, off Sturgeon Bay, Wisconsin, and Frankfort, Michigan, were combined with records for lower Lake Michigan.

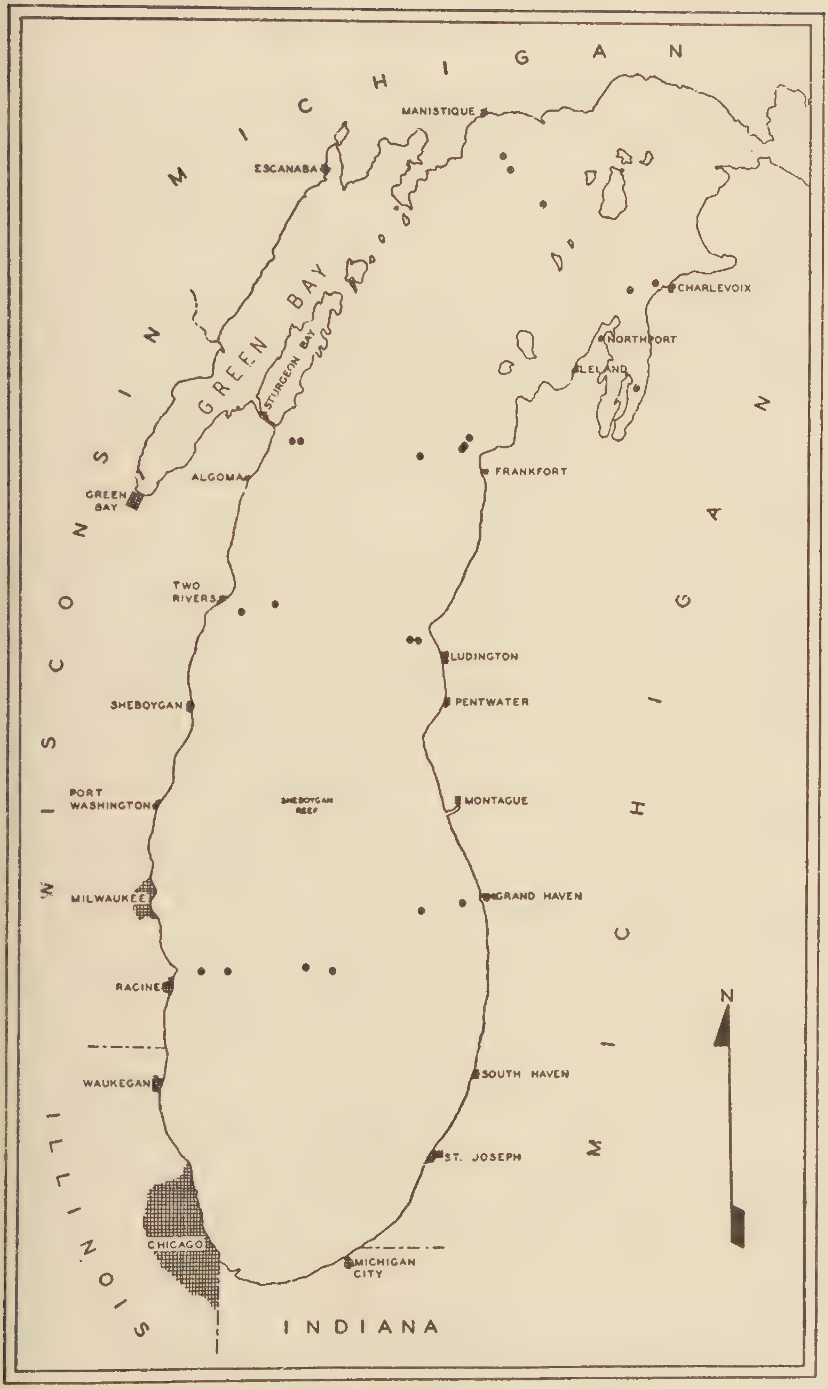

FIGURE 1.—Lake Michigan, showing localities of special interest in this study. The dots are fishing stations of the research vessel *Cisco*, 1954 and 1955.

inch-mesh nylon[5] and were fished for an average of about 7 nights (mean fishing time for 63 commercial lifts observed by biologists in 1950–1952). They did, however, bias to some degree comparisons between data for 1930–1932 and those for 1951–1955. Experimental nets fished in 1930–1932 were made of linen, had meshes from 2⅜ to 3 inches and were fished for an average of about 11 nights in 1930–1931 and 6 nights in 1932. A precise estimate of the relative efficiency of linen and nylon twine in taking lake trout is not offered, but it is certain that nylon is the more effective. In the capture of chubs it is estimated to be 2 to 3 times as efficient as cotton (Hile and Buettner, 1955) and cotton, in turn, is more effective than linen. In comparisons of data for 1930–1932 and 1951–1955, therefore, the figures for the earlier period must be recognized as underestimates.

In the 1930–1931 experimental fishing in lower Lake Michigan, nets of 2½-, 2⅝-, and 2¾-inch mesh took somewhat larger numbers of lake trout than did the 2⅜- and 3-inch-mesh nets. The differences were so small, however, that a combination of data for all mesh sizes was considered justified.

In general, the various biasing factors listed have no significant effect on the conclusions to be drawn from the data of the present paper. The changes in lake trout abundance after the invasion of the sea lamprey were so extreme that the small defects of the data can be termed trivial.

Decrease in abundance of lake trout in lower Lake Michigan.—The average numbers of lake trout caught per 1,000 feet of chub net lifted by commercial fishermen declined progressively each year from 1951 to 1955 along both shores of Lake Michigan (Table 2 and Fig. 2[6]). Comparisons of the rate of capture during the same months of successive years show an annual decrease for each value, with the exception of February 1953 on the east shore and of July, August, and November 1952 on the west shore. In both regions these exceptions to the trend were inconsequential. The 1952 data for the months indicated reflect a slight increase over 1951 in the rate of capture of lake trout off Waukegan. This local increase was not shown by fishing at any other port.

The catch per unit of effort for lake trout in 1951, when the rate of capture in chub nets was appreciably greater than in subsequent years, was only a small fraction of that in experimental gill nets of the *Fulmar* in 1930–1931. Estimates of the changes in abundance over the several years of this study (Table 3) show that catch per unit of effort in 1951 was only 3 to 4 percent of that of 1930–1931. The number of fish in this remnant of the lake trout population declined severely in each succeeding year. The greatest recent change in abundance took place in 1954, when drops of 83 and 93 percent occurred. Although the percentage decrease was even greater in 1955, lake trout of a size vulnerable to small-mesh nets had practically disappeared by 1954. In the first 7 months of that year (a

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[5] A conversion from the use of cotton to nylon twine in the chub fishery was under way during the early years of this period. The change, begun in 1946, was complete or nearly so in most ports by 1952 or 1953 (Hile and Buettner, 1955).

[6] Values for 1955 were too small to warrant inclusion in the figure.

[Number of thousands of feet of gill net in parentheses]

Month	East shore						West shore					
	[1]1930-31	1951	1952	1953	1954	1955	[1]1930-31	1951	1952	1953	1954	1955
January	....	....	....	0.48 (8)	....	....	....	....	0.62 (428)	0.19 (898)	0.01 (216)	....
February	....	....	0.38 (72)	0.50 (86)	0.00 (29)	....	....	....	0.42 (951)	0.10 (331)	0.05 (240)	....
March	....	....	1.72 (236)	1.03 (454)	0.03 (227)	....	....	....	0.39 (805)	0.22 (418)	0.05 (263)	....
April	....	....	2.03 (377)	0.95 (799)	0.12 (892)	0.01 (527)	....	....	0.48 (756)	0.35 (407)	0.04 (1,027)	[2]0.00 (802)
May	12.42 (46)	....	0.91 (652)	0.69 (910)	0.06 (1,078)	[2]0.00 (501)	12.51 (51)	....	0.32 (1,189)	0.12 (458)	0.03 (1,249)	0.00 (875)
June	11.33 (44)	0.97 (280)	0.36 (992)	0.22 (1,518)	0.02 (1,064)	0.00 (542)	7.68 (97)	0.40 (459)	0.18 (924)	0.07 (1,130)	0.01 (450)	0.00 (718)
July	18.34 (89)	0.61 (686)	0.24 (1,072)	0.05 (2,043)	0.01 (1,536)	[2]0.00 (644)	5.65 (79)	0.12 (1,250)	0.22 (1,047)	0.04 (1,208)	[2]0.00 (523)	0.00 (906)
August	19.90 (76)	0.39 (925)	0.26 (1,139)	0.06 (649)	....	....	4.12 (138)	0.07 (1,019)	0.09 (1,001)	[2]0.00 (240)	....	....
September	17.25 (37)	0.31 (496)	0.19 (936)	0.06 (518)	....	....	5.41 (59)	0.23 (560)	0.07 (988)	0.00 (264)	....	....
October	15.60 (31)	0.71 (441)	0.32 (573)	0.18 (622)	....	....	6.05 (99)	0.21 (552)	0.11 (753)	0.00 (276)	....	....
November	....	....	....	....	....	....	9.99 (79)	0.07 (205)	0.11 (97)	....	....	....
December	....	....	0.39 (336)	[2]0.00 (230)	....	....	....	0.62 (510)	0.23 (467)	[2]0.00 (216)	....	....

[1] Data from Van Oosten and Eschmeyer (1956)

[2] Less than 0.005.

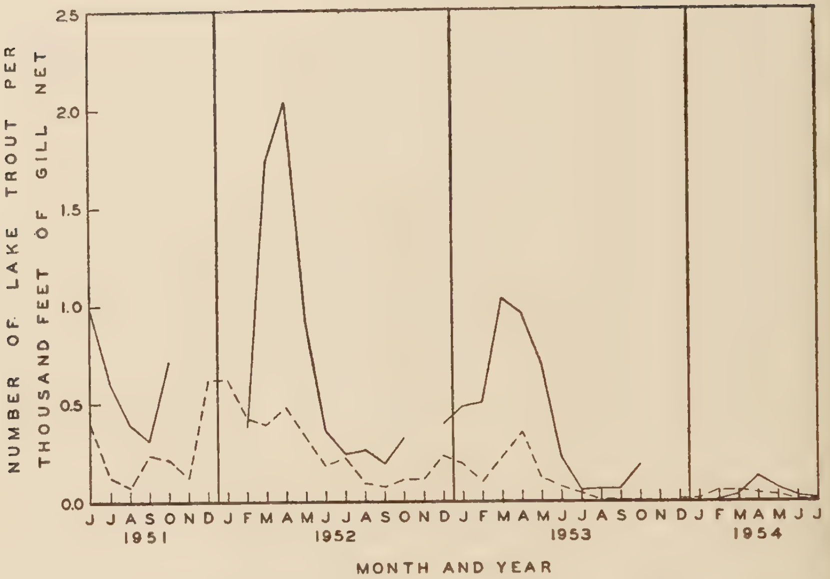

FIGURE 2.—Numbers of lake trout caught per 1,000 feet of small-mesh gill net lifted in Lake Michigan, 1951–1954. Solid line, east shore; dotted line, west shore.

period which includes the months when catch per net reached its seasonal peak in 1952 and 1953), 8,794,000 feet (1,666 miles) of gill net (data for east and west shores combined) took only 326 lake trout; in April–July 1955 only 8 lake trout were caught in 5½ million feet of gear.

In the graphical representation of the disappearance of lake trout in Lake Michigan (Fig. 2) both the annual downward progression of lake trout numbers and seasonal changes in catch per net during each year are

TABLE 3.—*Percentage decreases in abundance of lake trout in lower Lake Michigan, based on catches in small-mesh gill nets*

[Comparisons are restricted to those months during which fishing was done in both of the years compared. The number of monthly averages included in each comparison is shown in parentheses]

Region	Years compared				
	1930-31 and 1951	1951 and 1952	1952 and 1953	1953 and 1954	1954 and 1955
East shore	96 (5)	54 (5)	45 (10)	93 (6)	94 (4)
West shore	97 (6)	41 (7)	65 (11)	83 (7)	98 (4)

well defined. Curves of seasonal availability on both shores of the lake show a tendency toward a gradual rise to a peak in March or April, followed by a decline to the seasonal low in July, August, and September, and a gradual rise during the last quarter of the year. These annual and seasonal changes were still apparent when the data were stratified according to depth. They were present also in the records of individual operators.

Differences between lake trout abundance in 1930–1931 and in later years are demonstrated strikingly by the computation of the numbers of lake trout that would have been taken in each recent season if the rate of capture had been equal to that of experimental gill nets fished in 1930–1931 in the same region of the lake, month, and 10-fathom depth interval (Table 4). In 1952, for example, the "expected" catch of lake trout in 8,853,000 feet of gill net lifted in lower Lake Michigan was 103,462; the actual catch was only 2,542 or 2.5 percent. The percentage of the expected atch actually taken decreased progressively each year through 1955, when over 3 million feet of gear took only 2 fish, as compared with an expected catch of 35,026. The sharp decline in lake trout numbers from 1953 to 1954 is again clearly shown in Table 4, as it was in Tables 2 and 3.

Data on experimental fishing in Lake Michigan by the *Cisco* in 1954–1955 corroborate the data from the commercial fishery. In 1954, 57,000 eet of small-mesh gill net with an expected catch of 827 lake trout took only 2 fish; 96,000 feet of net lifted in 1955, which had an expected catch f 995 fish, took none. Of the gear lifted in 1954, 41,000 feet were linen, identical in construction and mesh size (2⅜ to 3 inches) to nets used by he *Fulmar;* 16,000 feet were nylon, with mesh sizes of 2¼ to 3 inches. n 1955, 68,000 feet of linen and 28,000 feet of nylon net (the latter with mesh sizes ranging from 2 to 3 inches) were lifted.

TABLE 4.—*Comparison of numbers of lake trout caught in commercial chub nets in lower Lake Michigan, 1952-1955, with numbers that would have been taken in the same nets if he rate of capture had been equal to that of experimental gill nets fished in 1930-1931*

[Included (bottom of table) is a comparison of experimental fishing in 1930-1931 and 1954-1955]

Year and kind of net	Thousands of feet of net	Expected catch[1] (number)	Actual catch	
			Number	Percentage of expected catch
Commercial				
1952	8,853	103,462	2,542	2.5
1953	7,889	96,957	1,347	1.4
1954	4,401	49,829	106	0.2
1955	3,193	35,026	2	[2]0.0
Experimental				
1954	57	827	2	0.2
1955	96	995	0	0.0

[1] Computed on the basis of fishing records of the *Fulmar* in 1930-1932 for the same region of the lake, 10-fathom depth interval, and month; from Van Oosten and Eschmeyer (1956)

Less than 0.05

In addition to the gill-netting operations by the *Cisco* in 1954 and 1955, otter trawls were dragged along the bottom over a wide range of depths, dates, and localities. No lake trout were caught during a total effective fishing time of 33 hours in 1954 and 9 hours in 1955 (capture of other species of fish proved that the trawl was operating satisfactorily).

Decrease in abundance of lake trout on the Sheboygan Reef.—A remarkable winter and spring concentration of lake trout on the Sheboygan Reef, an area approximately 30 miles east of Port Washington, Wisconsin, with water depths of about 25 to 40 fathoms, was revealed by the records of a fisherman operating in these waters during the years 1948–1955 (Table 5). Fishing throughout the 8-year period for which data are shown was within an 8-mile radius.

The rate of capture of lake trout in chub nets was much higher on the Sheboygan Reef than in other areas in the lake in 1951 and 1952. Thoughout the years 1948–1952, and as recently as February 1953, catches were strongly reminiscent of the fishing success of experimental nets fished by the *Fulmar* in 1930–1931, before the sea lamprey had invaded Lake Mich-

TABLE 5.—*Numbers of lake trout caught per thousand feet of 2½-inch-mesh gill net on the Sheboygan Reef, Lake Michigan, 1948-1955*[1]

[Number of thousands of feet of net in parentheses]

Year	February	March	April	May
1948	18.2 (32)	16.6 (42)	8.5 (53)	....
1949	19.7 (127)	16.5 (190)	9.8 (236)	6.8 (106)
1950	....	20.7 (106)	15.2 (185)	12.3 (106)
1951	10.6 (26)	14.6 (106)	12.1 (290)	7.2 (53)
1952	8.9 (92)	6.4 (373)	2.7 (197)	0.7 (106)
[2]1953	8.3 (211)	3.4 (271)	1.3 (42)	....
1954	0.7 (106)	0.3 (317)	0.4 (190)	....
1955	[3]0.0 (123)	[3]0.0 (317)	0.0 (169)	0.0 (211)

[1] For the years 1948-1953 the pounds (dressed weight) of lake trout given in monthly commercial fishing reports to the State of Wisconsin were multiplied by the factor 1.86 to obtain the values shown in the table. The average round weight of 2,147 lake trout caught in 2½-inch-mesh gill nets in lower Lake Michigan in 1930-1931 was 10.5 ounces (Van Oosten and Eschmeyer, 1956). The average loss of weight after dressing of 135 lake trout caught in 2½-inch-mesh nets lifted on the Sheboygan Reef March 3, 1953, was 18.3 percent. Values for 1954 and 1955 were supplied directly by the fisherman

[2] Catch in January 1953 was 16.1 lake trout per 1,000 feet in 84,000 feet of net. No fishing was done in this month during other years

[3] Less than 0.05

igan. In 1950, when the rate of capture of lake trout was highest, the estimates of catch per 1,000 feet of gill net for March to May ranged from 20.7 to 12.3. An annual decline began in 1951 and the catch decreased in subsequent years during each month for which records were available, until it was practically nil in 1955. The most significant decrease in this area, as elsewhere in the lake, occurred in 1954, when the catch dropped nearly 90 percent, from 4.3 lake trout per 1,000 feet of gill net in 1953 to 0.5 in 1954 (simple averages of values for 3 months). Lake trout continued to be more plentiful on the Sheboygan Reef in early 1954 than elsewhere in Lake Michigan, but the numbers vulnerable to small-mesh nets had, nevertheless, decreased drastically since the previous year. By early 1955 small lake trout were as rare in this former center of abundance as they were elsewhere in Lake Michigan.

Decrease in abundance of lake trout in northern Lake Michigan.—The data on catches of lake trout in chub nets in northern Lake Michigan (Table 6) were obtained from records of a single operator who fished periodically out of Manistique. Except for part of 1952, depth data are not available, and no records at all were obtained in 1953 or 1955.

TABLE 6.—*Numbers of lake trout caught per 1,000 feet of small-mesh gill net in northern Lake Michigan, 1932-1954*

[Number of thousands of feet of gill net in parentheses]

Month	[1]1932	1951	1952	1954
anuary	....	....	....	0.00 (152)
ebruary	... .	....	....	0.00 (410)
March	....	....	0.18 (261)	0.00 (86)
pril	....	....	0.20 (480)	....
May	....	....	0.03 (442)	....
une	5.57 (129)	0.26 (238)	0.04 (266)	....
uly	3.30 (199)	0.17 (525)	0.10 (176)	....
ugust	9.07 (199)	0.99 (538)	....	....
eptember	1.86 (93)	0.11 (406)	....	....
ctober	....	0.05 (402)	....	....

[1]From catch records of experimental gill nets fished by the *Fulmar*

Despite the scantiness of the data, they support the conclusions based on records for lower Lake Michigan. The catch per unit of effort in 1951 was a small fraction of that for the experimental nets of the *Fulmar* in 1932; the take declined further in 1952; and in 1954 not one lake trout was caught in 648,000 feet of gill net.

Belief that the lake trout is nearing extinction in northern as well as in southern Lake Michigan is supported by the experimental fishing of the *Cisco* in 1955. Only 1 lake trout was caught in 62,000 feet of small-mesh experimental linen and nylon gill net.

TABLE 7.—*Percentage length-frequency distribution of lake trout caught in 2½-inch-mesh gill nets in Lake Michigan, 1930-1952*

[Data for 1930-31 and 1932 are from Van Oosten and Eschmeyer (1956). Dates, localities, and (in parentheses) numbers of fish composing other collections in lower Lake Michigan were as follows: 1950 — June 10-29, Frankfort, Pentwater, and Ludington (238) and August 22-25, Grand Haven and St. Joseph (54); 1952 — April 23, Michigan City (56), April 28-30, Port Washington, Sheboygan, and Sturgeon Bay (45), and May 5, Frankfort (15). Data for northern Lake Michigan in 1950 were collected at Charlevoix and Manistique, June 9-July 15. See Fig. 1 for locations]

Total length (inches)	Lower Lake Michigan			Northern Lake Michigan	
	1930-1931	1950	1952	1932	1950
8.0- 8.9	0.1	....	....	....	....
9.0- 9.9	....	0.7	....	....	....
10.0-10.9	1.2	1.7	4.3	....	0.9
11.0-11.9	15.4	24.7	18.1	4.2	10.3
12.0-12.9	38.6	32.9	24.1	26.2	17.8
13.0-13.9	26.9	18.8	22.4	31.0	24.3
14.0-14.9	10.1	9.3	12.1	19.3	18.7
15.0-15.9	3.8	5.2	8.6	11.1	15.4
16.0-16.9	1.7	4.8	4.3	3.8	8.4
17.0-17.9	1.0	1.0	3.5	2.4	2.8
18.0-18.9	0.4	0.3	1.7	1.0	1.4
19.0-19.9	0.1	0.3	....	0.4	....
>19.9	0.7	0.3	0.9	0.6	....
Number of fish	1,826	292	116	1,007	214
Average length (inches)	13.5	13.1	13.5	13.9	14.0

FACTORS IN THE DECLINE OF LAKE TROUT IN LAKE MICHIGAN

Three factors which require consideration in an appraisal of the cause of the near extinction of lake trout in Lake Michigan are: the destruction of lake trout in the small-mesh nets of the chub fishery; the destruction of lake trout by the sea lamprey; and the near or perhaps complete failure of natural reproduction of lake trout by 1949 or 1950. To treat these factors effectively it is necessary to have some knowledge of the size and age of lake trout taken in chub nets.

The modes of the length-frequency distributions of lake trout caught in 2½-inch-mesh nets in lower Lake Michigan in 1930–1931, 1950, and 1952 were at the 12.0- to 12.9-inch interval; average lengths ranged from 13.1 to 13.5 inches (Table 7). In northern Lake Michigan, the mode was at 13.0–13.9 inches in both 1932 and 1950; the mean lengths were 13.9 and

4.0 inches, respectively. For each of these years, and in both regions, 76 to 1 percent of the lake trout were within a 4-inch interval of length (11.0–4.9 inches in lower Lake Michigan and 12.0–15.9 inches in the northern gion).

Van Oosten and Eschmeyer (1956) reported that 4-year-old fish composed 54 percent of 127 lake trout caught in 2½-inch-mesh gill nets in 930–1932; fish of age-group III made up 25 percent, and the V group, 4 percent. Comparison of their age determinations for 575 lake trout and Cable's (1956) records for 738 small lake trout caught in 1947–1951 (Table 8), with the length-frequency distributions (Table 7), support the ew that these age groups must have been the principal ones caught in hub nets.

TABLE 8.—*Average total lengths (inches) of lake trout collected in Lake Michigan*

Years of collection	Length at end of year of life[1]						
	1	2	3	4	5	6	7
30-1932	3.4	7.1	11.7	13.0	14.4	16.8	18.6
47-1951	5.6	8.6	10.9	13.3	15.8	17.8	....

[1] The data for 1930-1932 are based on both calculated and actual measurements (Van Oosten and Eschmeyer, 1956); lengths for 1947-1951 were obtained by the summation of calculated increments, for marked hatchery trout released in Lake Michigan as fingerlings in the fall of 1944, 1945, and 1946, and recovered in 2½-inch-mesh gill nets (Cable, 1956)

Destruction of small lake trout in chub nets.—The results of experimental fishing of the *Fulmar* in 1930–1932 (Tables 2 and 6), and other observations, demonstrated clearly that, during years of normal abundance, rge numbers of small lake trout were killed by the small-mesh nets of the hub fishery. Statistics of the commercial fishery for State of Michigan aters of Lake Michigan in 1929–1954, however, give no indication that his loss had any effect on the later abundance of lake trout (Table 9).

Fluctuations in the intensity (and thus the potential destructiveness) of he chub fishery and later changes in abundance of lake trout were not orrelated. In 1935–1938, a period of high fishing intensity in the chub shery, the estimated number of small lake trout caught in State of Michigan waters ranged from 688,000 to 927,000. These estimates were the ghest for any years in the period 1929–1947, and in 3 of the years 935, 1936, 1938) greater numbers of lake trout were estimated to have een killed in the chub fishery than were caught in the commercial fishery r lake trout of legal size. Nevertheless, in 1939–1944, within the period hen this destruction should have had its maximum effect in reducing the mber of fish available to the commercial fishery, trout production in ate of Michigan waters averaged 2,802,000 pounds per year—a value gher than for any equivalent period in the years 1929–1953. The abundance index for lake trout in 1939–1944 ranged from 100 to 126 percent of e 1929–1943 average.

TABLE 9.—*Estimated numbers of lake trout caught in the chub fishery and in the lake trout fishery in State of Michigan waters of Lake Michigan, 1929-1953*

Year	Chub fishing		Commercial production of lake trout		Abundance index of lake trout[5]
	Units of 10,000 feet of small-mesh gill net lifted[1]	Potential number of lake trout caught (thousands)[2]	Thousands of pounds[3]	Thousands of individuals[4]	
1929	3,234	380	2,198	733	87
1930	3,229	372	2,556	852	83
1931	2,234	273	2,652	884	87
1932	1,735	225	2,746	915	96
1933	1,615	196	2,379	793	97
1934	3,632	424	2,053	684	98
1935	7,355	922	2,451	817	102
1936	7,609	927	2,127	709	97
1937	5,656	688	2,264	755	93
1938	6,957	864	2,480	827	92
1939	4,920	674	2,778	926	105
1940	1,491	191	2,780	927	100
1941	1,734	206	3,189	1,063	123
1942	1,806	214	2,641	880	114
1943	1,487	209	2,814	938	126
1944	1,453	167	2,609	870	110
1945	2,767	321	2,228	743	98
1946	2,786	337	1,908	636	75
1947	4,188	576	914	305	60
1948	6,452	924	589	196	50
1949	7,604	1,017	223	74	26
1950	6,508	876	25	8	.....
1951	6,701	867	2	1	.....
1952	7,266	965	.....	.....	.....
1953	8,551	1,121	.....	.....	.....
1954	8,556	1,150	.....	.....	.....

[1] From Hile and Buettner (1955)

[2] Based on average numbers of lake trout caught in experimental gill nets by the *Fulmar* in 1930-1932 (Van Oosten and Eschmeyer, 1956). These averages were 54 per 10,000 feet of net in northern Lake Michigan and 165 in State of Michigan waters of lower Lake Michigan

[3] Data for 1929-1949 from Hile, Eschmeyer, and Lunger (1951)

[4] Average weight in the commercial catch in the Great Lakes suggested by Van Oosten (1944) was from 3 to 10 or 12 pounds. The smallest value was used in converting from pounds to numbers of individuals

[5] Percentage of 1929-1943 mean

In 1940–1944, in contrast, the intensity of fishing for chubs was markedly lower than in 1935–1938; the potential numbers of small lake trout destroyed ranged from 167,000 to 214,000 per year, the lowest values in the period 1929–1954 (except 1933). In these years only 19 to 24 percent as many trout were estimated taken in the chub fishery as in the lake trout fishery. However, the lake trout fishery collapsed in the late 1940's, when the fishery should have benefitted most from the decreased destruction of small lake trout in the chub fishery of 1940–1944.

The statistics of the chub and lake trout fisheries in State of Michigan waters of Lake Michigan, therefore, give no indication that the catch of small lake trout in the chub fishery had any effect on the later abundance of lake trout of commercial size. It was not a significant factor either in the collapse of the lake trout fishery or in the recent scarcity of small trout. In o far as is known, the sea lamprey was primarily, and perhaps solely, reponsible for the near extinction of lake trout in Lake Michigan.

The destruction of lake trout by the sea lamprey.—The action of the sea amprey in bringing lake trout of Lake Michigan near to extinction was wofold. First, the stock was reduced directly by lethal attacks of the paraite on the trout. Second, recruitment to the stock diminished and most robably came to an end when spawning stocks decreased so that natural eproduction became less and less effective. It is not possible to estimate recisely the relative importance of the two factors for any calendar year. t can, nevertheless, be demonstrated that enormous declines took place in he abundance of lake trout well in advance of the time when failure of atural reproduction could have been a factor and also to offer evidence hat by 1949 or 1950 little spawning was taking place.

The tracing of the decline of lake trout was handicapped by the necesary change from records of catch per unit of effort in commercial trout ear (most production from large-mesh gill nets) to the records of small sh caught in chub gill nets. The decline in abundance of lake trout during he late 1940's made trout fishing so unprofitable that fishing intensity also nderwent a rapid decline (Table 10). By 1950 the levels of production nd fishing effort were so low that the routine estimation of abundance was bandoned. Subsequent to 1949, therefore, information on abundance of ke trout had to come almost exclusively from records of small trout in hub nets obtained by field observers or submitted by cooperating fisheren.

TABLE 10.—*Production and abundance of lake trout in Lake Michigan, 1943-1950*

Year of spawning	Production of lake trout		Abundance index of lake trout in State of Michigan waters[2]	Index of fishing intensity for lake trout in State of Michigan waters[2]	Year when young were 4 years old
	Thousands of pounds[1]	Percentage of 1940-1944 mean			
43	6,860	104	126	88	1948
44	6,498	99	110	92	1949
45	5,437	83	98	87	1950
46	3,974	60	75	91	1951
47	2,425	37	60	61	1952
48	1,197	18	50	50	1953
49	342	5	26	26	1954
50	54	1	..	..	1955

ata for 1943-1949 from Hile, Eschmeyer, and Lunger (1951)

ercentage of 1929-1943 mean

Inasmuch as large- and small-mesh gill nets capture lake trout of differnt sizes, the question arises as to whether the rates of decline of large and nall lake trout were the same or at least similar. If they were, records om chub nets can be used to extend to more recent years the descripon of the decline of lake trout that Hile, Eschmeyer, and Lunger (1951) ere able to carry through 1949 from statistics on the trout fishery. Inormation on this question, although not plentiful, indicates strongly that declines in abundance of legal-sized trout and of small trout of the size caught in chub nets followed similar courses. The first of the recent records on catches of small lake trout in chub nets in Lake Michigan was obtained in May 1949 by biologists who observed the lifting of 160,000 feet of small-mesh gill net off Frankfort, Michigan. These nets contained 228 lake trout or 1.4 fish per 1,000 feet. Nets lifted in 1930–1931 by the *Fulmar* in the same region of the lake, in the same month, and from the same depth, took 20.4 per 1,000 feet. The abundance of small lake trout off Frankfort in 1949, therefore, was only 7 percent of that in 1930–1931. In the same year the abundance index for legal-sized trout in the Frankfort district was 35 percent of the 1929–1943 mean (the index was 79 in 1930 and 71 in 1931). According to these figures the decline in abundance of lake trout off Frankfort by 1949 was more severe among small than among legal-sized fish.

Field observations of 1950 agreed with those of 1949. In June–August 1950, biologists observed catches in 324,000 feet of chub nets along the east shore between Charlevoix and St. Joseph, Michigan. The average catch of 1.0 trout per 1,000 feet was only 4 percent of the rate in *Fulmar* nets fished under comparable conditions. Information on the abundance of legal-sized lake trout in 1950 is limited to that obtained from observations on 128,000 feet of large-mesh net lifted off Frankfort, Charlevoix, and Manistique, Michigan, June 7–July 15. The total catch of 136 pounds of legal-sized fish represented a rate of capture of 8 percent of the 1929–1943 average. In 1950, as in 1949, therefore, both legal-sized and small lake trout were extremely scarce, and again the abundance of small fish was relatively lower than that of large ones.

The 1949 and 1950 observations indicate that large and small lake trout both declined over the same general period of years and that by these years the decline may have been greater among small fish.

The low level of abundance of small lake trout in 1949 and 1950 and the subsequent annual decreases to 1954 are believed to be largely the direct result of lethal attacks by sea lampreys. Failure of natural reproduction is held first to have exerted a major influence in 1954. Arguments in support of this view are based on evidence as to the abundance of spawners in the calendar years that contributed the dominant age group of later years, on the sudden drop in the catch of small trout in 1954, and on the sudden rise in 1954 in the percentage of legal-sized lake trout in the chub-net catches

The statistics of Table 10 on the production of legal-sized lake trout in all of Lake Michigan and on their abundance in State of Michigan waters provide a fair measure of the abundance of spawners in different calendar years. This measure is not perfect, however, because not all legal-sized fish are sexually mature (Table 11). The fish examined in 1947 included numbers of immature lake trout of both sexes larger than the minimum legal sizes of 17 inches (Wisconsin) and 1½ pounds (Illinois and Michigan). Furthermore, the percentages of immature fish at various lengths undoubtedly would have been much greater if the samples had not come from spawning or pre-spawning aggregations which normally are domin ated by mature individuals.[7] Because the smaller legal-sized lake trout include immature fish, the percentage of spawners among legal-sized fish must vary with fluctuations in the size distribution. The extent of such annual fluctuations is not known, but in 1948, as in 1947, large fish were plentiful in the catch.

If the data of Table 10 are accepted as indicative of general trends of abundance of mature lake trout, substantial numbers were present and were caught through 1948. In that year the catch in the entire lake was still well above a million pounds and the abundance index in State of Michigan water was 50 percent of the 1929–1943 mean. Fish from the 1948 spawning hatched in 1949 and could be expected to dominate chub-net catches of lake trout as age-group IV in 1953. Although conditions in 1948 can hardly be termed good, they were much worse in 1949. Production dropped 71 percent and the abundance index (26) was barely half that of 1948. Further deterioration occurred in 1950.

TABLE 11.—*Length distribution of lake trout collected in Lake Michigan, 1947-1948*

in 1947 fish were collected October 9-23 in 4½-, 5-, and 5¼ inch-mesh gill nets off Frankfort, Montague, South Haven, and St. Joseph, Michigan, and Waukegan, Illinois; 1948 collections were on September 22-October 8 in 4½-, 4¾-, 5-, and 5¼-inch-mesh gill nets off Charlevoix, Leland, and Northport, Michigan, and Waukegan. Sex and maturity were not determined in 1948]

Total length (inches)	Year of collection							
	1947							1948
	Males			Females			Total number of fish	Total number of fish
	Immature	Mature	Percentage mature	Immature	Mature	Percentage mature		
<17.0	1	...	0	4	...	0	5	76
17.0-17.9	1	...	0	4	...	0	5	47
18.0-18.9	2	...	0	3	1	25	6	39
19.0-19.9	3	2	40	3	1	25	9	39
20.0-20.9	2	20	91	8	...	0	30	56
21.0-21.9	2	102	98	8	7	47	119	56
22.0-22.9	..	133	100	18	37	67	188	51
23.0-23.9	1	94	99	9	70	89	174	42
24.0-24.9	..	79	100	7	91	93	177	43
25.0-25.9	..	50	100	1	62	98	113	38
26.0-26.9	1	26	96	..	35	100	62	25
27.0-27.9	..	7	100	..	22	100	29	20
28.0-28.9	..	3	100	..	6	100	9	23
> 28.9	..	...	...	[1]1	7	88	8	33
Total	13	516	...	66	339	...	934	588

[1] This non-spawning female was 31.2 inches long. The 7 mature fish were 29.7 to 34.3 inches in length

The evidence from Table 10 that natural reproduction may have become largely ineffective in 1949 is not in itself conclusive. It is supported, however, by the tremendous drop in the catch of lake trout in chub nets (Tables 2–4) from 1953 when the normally dominant IV group came from the 1948 spawning to 1954 in which year IV-group fish came from the 1949 spawning. Further evidence of sparse recruitment in 1954 is provided by the following record of the percentage of legal-sized lake trout in the catch of chub nets, made available by cooperating fishermen of Michigan City Indiana, and St. Joseph, Michigan:

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[7] Lake trout in lower Lake Michigan matured at a much smaller size than in southern Lake Superior (Eschmeyer, 1955) or western Lake Ontario (Dymond, 1928). In fish from spawning or pre-spawning aggregations collected in southern Lake Superior, September 8-November 8, 1950, most males less than 24 inches and females less than 27 inches long were immature.

Year	*Number of fish*	*Percentage legal-sized*
1951	1,113	5
1952	1,616	9
1953	1,749	15
1954	153	52
1955	4	75

The percentage of legal-sized lake trout increased gradually from 5 in 1951 to 15 in 1953 but in 1954 it rose sharply to 52. In view of the far lower vulnerability of legal-sized than of smaller fish to chub gill nets, the predominance of the larger lake trout in southeastern Lake Michigan in 1954 was actually much greater than this percentage indicates.

The evidence that the decline of lake trout of all sizes down to those captured in chub gill nets was caused primarily by lethal attacks of sea lampreys and that failure of natural reproduction was of minor importance until 1954, after the major decline had occurred, makes possible the explanation of the correlation between the size of lake trout and the percentage of individuals bearing sea lamprey scars. The relationship described by Van Oosten (1949) between the length of Lake Michigan trout and the percentage of individuals with scars is typical of that observed repeatedly in lake trout populations subject to sea lamprey predation. In Van Oosten's samples the percentage of scarred fish was small (0.5 percent) among fish less than 17 inches long but rose rapidly and consistently with increase in length of fish to a value of 80.0 percent for lake trout 24.5 to 35.4 inches long. Although Van Oosten did not undertake an explanation of this relationship, the alternatives are obvious. Either sea lampreys attack lake trout selectively, favoring the larger fish, or the ability of trout to survive lamprey attacks increases with size of fish. The data of the present study favor overwhelmingly the second explanation. Especially pertinent is the evidence that the abundance of small lake trout apparently decreased more rapidly than that of legal-sized individuals.

An increase in ability to survive sea lamprey attacks with increase in size of fish may explain also the relation between scarring and the length of white suckers described by Hall and Elliott (1954).

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Diet-Induced Differences in the Weight—Length Relationship of Aquarium Fed Sardines (*Sardinops caerulea*)[1,2]

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INTRODUCTION

IN the course of aquarium experiments designed to reveal diet induced changes if any) in the free amino acid pool of fish muscle, some data were obtained on oncurrent changes in the weight-length relationship of the fish fed on two different iets. The data and interpretation of these weight–length changes are presented ere; the results and interpretation of the amino acid analysis will be presented lsewhere.

METHODS

In the spring of 1954 Steinhart Aquarium received approximately 1500 ardines (Radovich, 1954). These fish were taken in Hipolita Bay, Baja California, and are believed to be representative of a single population.

Four tanks were made available by the California Academy of Sciences for e experiments. Each was approximately 4 feet by 2 feet and 3 feet deep, and ontained about 160 gallons of water. The tanks were made of leached redwood. and-filtered sea water was continuously cycled through the tanks. Throughout e course of the experiment the water temperature ranged from 66°–71°F., with maximum daily range of ± 0.5°F.

The four tanks (C_1, C_2, P_1, P_2) were each stocked with 25 sardines. These h were withdrawn from the main stock tank without conscious selection. An dditional sample of 25 sardines was sacrificed at the start of the experiment and e designated as "Control". These fish were in a starved or semi-starved contion. Fish in tanks C_1 and C_2 were fed a carbohydrate diet. Fish in tanks P_1 and were fed a protein diet. The fish were fed a ration of 4 grams (dry weight) food per fish per day. The ration was divided into a morning and afternoon eding.

The carbohydrate diet consisted of tapioca dyed red to simulate brine rimp (upon which sardines will feed in captivity). This diet contained less an .0025 grams of amino acid per gram of food as determined by acid hydrolysis kinner *et al.*, 1940) and ninhydrin color test (Lederer and Lederer, 1953). The pioca was about 90% carbohydrate. The protein diet consisted of fish meal, icken eggs, vitamin supplement and fish liver oil. This material was homogend and fed as dry pellets. On acid hydrolysis it yielded the following amino ids: aspartic acid, glutamic acid, glycine, threonine, alanine, tyrosine, trypto-

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[2] Published by permission of the Director, U. S. Fish and Wildlife Service.

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nted in Canada.

phan, proline, leucine, valine, lysine and serine as determined by paper partitio chromatography (Brimley and Barrett, 1954). This diet was about 57% protei and about 7% carbohydrate. No attempt was made to estimate the amount o micro flora and fauna in the tanks, but it was considered to be negligible.

The experimental fish were maintained on these diets for a period of si weeks and then sacrificed. Their weights and lengths were recorded, and bod cavity fat was noted. A chromatogram was made of a sample of the pectora muscle.

RESULTS

The weights and lengths of the 93 fish, distributed among five groups, ar recorded in Appendix I. The fish which died (32) prior to the end of the experi ment were not considered in the regression analyses (Fig. 1). The straight lin

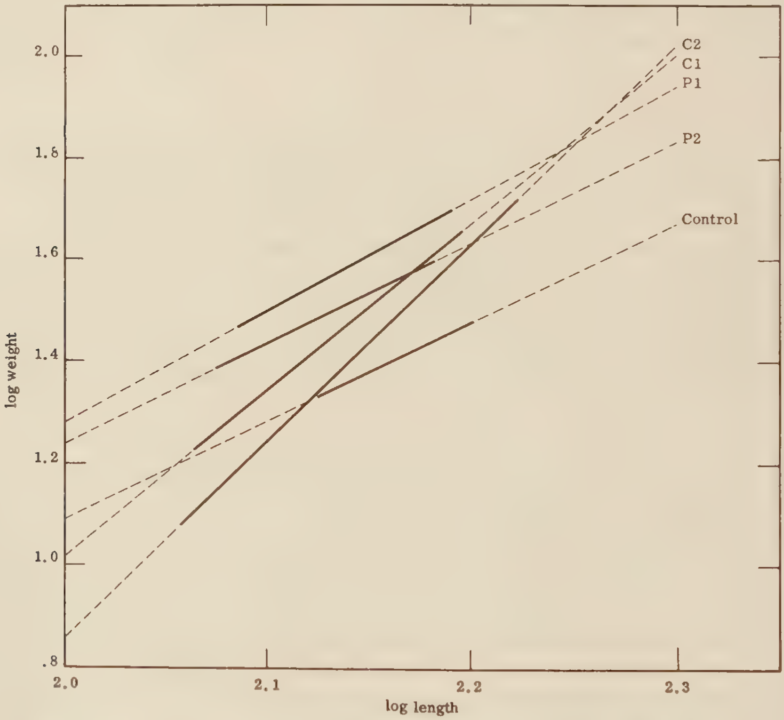

FIG. 1.—Log weight–log length regressions for five groups of sardines.

regressions of log weight on log length strongly suggest a difference in th weight–length relationship of the two diet groups. In order to test the reality o this difference, analysis of covariance procedures were used. (See any standar statistical text, such as Kendall, 1948.) The regression analyses are given i Tables I–IV and the regression statistics are summarized in Appendix II.

Comparison of diet group P_1 with diet group P_2 shows no difference in eithe slope or level of the regressions. The appropriate test is

$$F_{2,31} = \frac{S_2 + S_4}{df} \Big/ \frac{S_1}{df} = 0.138 < F_{2,31(.95)} = 3.3 \text{ (see Table I).}$$

P_1 and P_2 data were combined and then used as a single regression, (P), since there was no difference in the log weight–log length regression of the fish in the two tanks.

The Control fish were then compared with P fish. The general test showed that there was a difference in slope and/or level

$$(F_{2,56} = 89.607 > F_{2,56(.95)} = 3.16).$$

The appropriate test for comparing slopes is

$$F_{1,56} = \frac{S_2}{df} \Big/ \frac{S_1}{df} = .0098 < F_{1,56(.95)} = 4.02;$$

the slopes do not differ. Comparison of levels,

$$F_{1,57} = \frac{S_4}{df} \Big/ \frac{S_1 + S_2}{df} = 182.372 > F_{1,57(.95)} = 4.01,$$

shows that they differ. The analysis is given in Table II.

Comparison of diet group C_1 with diet group C_2 showed that there was no lifference in either slope or level (see Table III). These data were combined nto a single regression ($C_1 + C_2 = C$).

The slope of groups P and Control, combined, were then compared with the lope of groups C, combined; the slopes proved to be different (Table IV).

In order to relate the experimental weight–length data to what may be conidered a normal or natural condition, the weight–length data from the San edro fishery (Clark, 1928) were also plotted in Figure 2. The slope (3.15) of he San Pedro regression corresponds more closely with what was found for arbohydrate-fed fish (C_1, C_2) than with what was found for protein-fed fish.

ABLE I.—Sums of squares, products and regressions of log lengths (l) in millimeters and log weight (w) in grams for replicates of protein diet.

ource of ariation	Degrees of freedom	Σl^2	Σw^2	Σlw	Regression coefficients
Vithin P_1	15	.0116028	.1030096	.0255327	2.20056
Vithin P_2	18	.0186601	.1088586	.0367610	1.97003
Vithin P_1 and P_2	33	.0302629	.2118682	.0622937	2.058418
etween groups	1	.0018125	.0115132	.0045679	2.52022
otals	34	.0320754	.2233814	.06686159	2.084513

	Degrees of freedom	Sums of squares	Mean squares
eviations from individual regression	31	$S_1 = .0832616$	.00269729
ifferences between slopes of individual regressions	1	$S_2 = .0003802$	.0003802
eviations from regression with common slope	32	$S_1 + S_2 = .0836418$	.00261381
eviations of groups from means regression	0	$S_3^* = .00000$	. . .
ifference between slope of means regression and common slope	1	$S_4 = .0003657$	.0003657
Totals	33	.0840075	. . .

*S_3 has been retained throughout to indicate the extent of the rounding error.

TABLE II.—Sums of squares, products and regressions of log lengths (l) in millimeters and log weights (w) in grams for protein diet and "control".

Source of variation	Degrees of freedom	Σl^2	Σw^2	Σlw	Regression coefficients
Within P	34	.0320753513	.2233814	.0668615873	2.084516
Within "Control"	24	.0084951362	.0854757	.0172041547	2.025177
Within Groups	58	.0405704875	.3088571	.0840657420	2.072091
Between Groups	1	.0001371141	.4010019	−.007415033	−54.07929
Totals	59	.0407076016	.7098590	.076650689	1.88296

	Degrees of freedom	Sums of squares	Mean squares
Deviations from individual regression	56	$S_1 = .1346415$	.002404313
Differences between slopes of individual regressions	1	$S_2 = .0000236$	.0000236
Deviations from regression with common slope	57	$S_1 + S_2 = .1346651$	.002362546
Deviations of groups from means regression	0	$S_3 = .00000$	...
Difference between slope of means regression and common slope	1	$S_4 = .4308639$	.4308639
Totals	58	.5655290	...

TABLE III.—Sums of squares, products, and regressions of log lengths (l) in millimeters and log weights (w) in grams for replicates of carbohydrate diet.

Source of variation	Degrees of freedom	Σl^2	Σw^2	Σlw	Regression coefficients
Within C_1	12	.0148485	.1691975	.0488176	3.287713
Within C_2	19	.0354281	.5734579	.1356846	3.829858
Within C_1 and C_2	31	.0502766	.7426554	.1845022	3.669743
Between Groups	1	.0047144	.0866812	.0202148	4.287883
Totals	32	.0549910	.8293366	.2047170	3.722736

	Degrees of freedom	Sums of squares	Mean squares
Deviations from individual regression	29	$S_1 = .0625044$	.0021553
Differences between slopes of individual regressions	1	$S_2 = .0030753$	.0030753
Deviations from regressions with common slope	30	$S_1 + S_2 = .0655797$	.00218599
Deviations of groups from means regression	0	$S_3 = .0000$	...
Difference between slope of means regression and common slope	1	$S_4 = .001649$	.001649
Totals	31	.0672292	

TABLE IV.—Sums of squares, products and regressions of log length (l) in millimeters and log weight (w) in grams for protein diet-control and carbohydrate diet.

Source of variation	Degrees of freedom	Σl^2	Σw^2	Σlw	Regression coefficients
Within C	32	.0549910	.8293366	.2047170	3.72274
Within Control	59	.0407076	.7098590	.0766507	1.88296
Within Groups	91	.0956986	1.5391956	.2813677	2.94014
Between Groups	1	.0225600	.3800211	.0925906	4.10419
Totals	92	.1182586	1.9192167	.3739583	3.16221

	Degrees of freedom	Sums of squares	Mean squares
Deviations from individual regression	89	$S_1 = .6327582$	.00710964
Differences between slopes of individual regressions	1	$S_2 = .0791757$	.0791757
Deviations from regression with common slope	90	$S_1 + S_2 = .7119339$	.007910377
Deviations of groups from means regression	0	$S_3 = 0.0000$	...
Differences between slope of means regression and common slope	1	$S_4 = .0247488$	.0247488
Totals	91	.7366827	

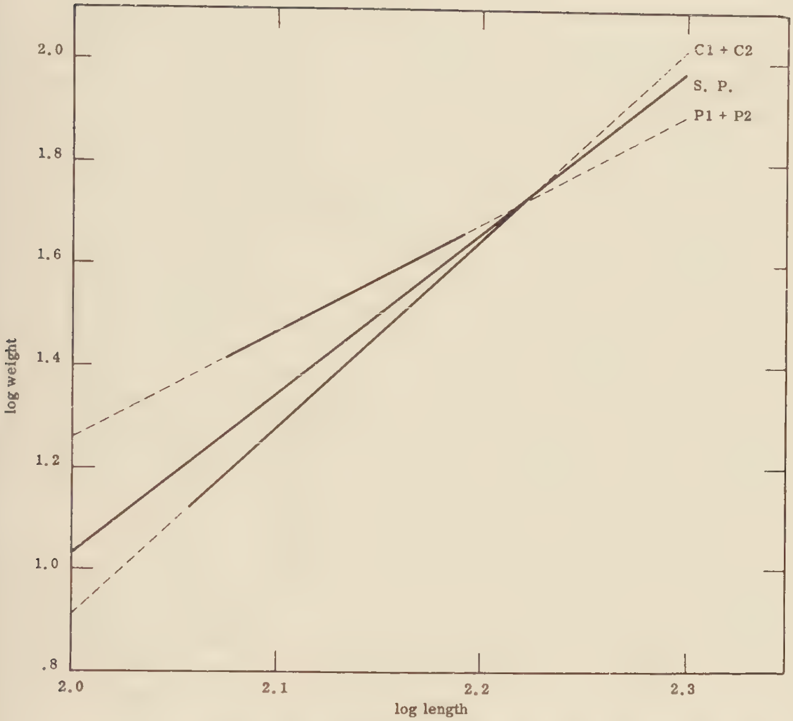

FIG. 2.—Log weight–log length regressions for three groups of sardines.

From dissection of the fish, the following was observed: Control fish were generally poor condition with no body fat. The carbohydrate-fed sardines $_1$ and C_2) were in a better condition with traces of body fat. The protein-fed (P_1 and P_2) were in good condition with fat in the body cavities of all cimens.

DISCUSSION

It is quite possible that the apparent gain in weight of the carbohydrate-fed is due to an accelerated uptake of water. It is to be noted, however, that the tulated uptake of water exceeded that of mere replacement. One is also perxed by the fact that the larger fish added a disproportionately larger weight rement of their body weight when fed on a carbohydrate diet. Unfortunately, fish were destroyed before the data were analyzed. However, an alternative othesis may be devised from the following considerations.

The differences in slope of the regressions are then to be regarded as real. nature a sardine diet is mainly zooplankton (Radovitch, 1952), which is relaly high in protein. This type of diet gives rise to a weight–length regression ing a slope of about 3.0 to 4.0. It is inferred that during starvation the larger lose weight at a greater rate than do smaller fish (because they have more stores to use), resulting in a lesser slope of the regression of log weight on log length. This would produce a regression similar to Control in slope. Now if these starved fish suddenly receive a "normal" to excess ration containing protein nitrogen (as in the P_1 and P_2 groups), it is possible that this added protein nitrogen brings about an increased cell production resulting in an increase in length. If, on the other hand, the "normal" to excess ration contains little or no nitrogen (as in the C_1 and C_2 groups), then the increase may be limited to the cells already present. The cells could increase their fat and carbohydrate stores up to a maximum, but no new cells could be added. This being the case, carbohydrate-fed fish would approximate the normal weight–length relationship more quickly than those fed on protein diet where lineal growth is possible. Had the fish fed on protein been maintained for a longer period of time, this weight–length regression should have the same slope as the normal, but the means should be displaced upward and to the right (i.e., the level would be greater). The lesser slope of the regression for protein-fed fish may be regarded as the result of a short term enhancement of cell production induced by the sudden flooding of the starved organisms with protein nitrogen.

SUMMARY

1. The weight–length relation of lots of 25 sardines fed different diets were compared. The diet history of these fish was (1) starved or semi-starved (one lot), (2) protein diet (two lots) and (3) carbohydrate diet (two lots).

2. The weight–length regressions of the two protein-fed lots do not differ in slope or level.

3. The weight–length regressions of the protein-fed fish (both lots combined) and the starved (Control) lot differ in level, but not in slope.

4. The weight–length regressions of the two lots of carbohydrate-fed fish do not differ in slope or level.

5. The weight–length regressions of protein-fed and Control fish (three lots combined) and the carbohydrate-fed fish (both lots combined) differ in slope.

6. The slope of the weight–length regression of carbohydrate-fed fish more closely approximates that of "wild" fish landed at San Pedro, than does the slope of the protein-fed fish.

7. The increase in weight of the carbohydrate-fed fish may be due to water uptake.

8. These observations may be explained by the fact that the carbohydrate-fed fish were able to increase their stores of fat and carbohydrate but were not able to add new cells, whereas the protein-fed fish were able to add new cells and thus increase in length.

ACKNOWLEDGMENTS

I wish to thank Mr. Anatole Loukashkin, California Academy of Sciences, for his assistance in feeding the fish. The technical assistance of Mr. Harold Haas, Tropic Waters Aquarium, who provided valuable information concerning fish diets is gratefully acknowledged. Mr. John MacGregor, U.S. Fish and Wildlife Service, made all the measurements of these fish. I wish also to thank Dr. R. C. Miller and Dr. Earl S. Herald, California Academy of Sciences, for making avail-

able the facilities of Steinhart Aquarium. Mr. Bruce Taft, U.S. Fish and Wildlife Service, aided in the preparation of the statistics.

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APPENDIX I.—Lengths and weights of sardines surviving at the end of the experiment.

Control		C_1		C_2		P_1		P_2	
Length	Weight	Length	Weight	Length	Weight	Length	Weight	Length	Weight
mm.	*grams*	*mm.*	*grams*	*mm.*	*grams*	*mm.*	*grams*	*mm.*	*grams*
144	24	116	15	143	30	130	29	151	52
140	22	157	41	117	16	145	35	150	36
149	28	143	32	131	18	148	50	145	45
147	30	145	37	123	18	155	49	145	37
142	26	148	31	167	52	122	28	135	37
135	27	142	30	135	24	151	34	148	38
141	18	122	19	123	20	142	40	152	41
141	26	129	21	126	20	139	36	149	40
139	22	141	32	120	12	144	39	149	38
139	22	131	24	121	16	142	35	129	31
149	26	136	27	131	22	150	34	128	31
147	29	137	28	114	12	149	52	119	24
136	24	139	30	122	19	150	40	148	41
152	30			152	38	155	46	137	42
144	24			138	27	153	49	143	37
134	25			114	12	147	46	140	36
154	32			126	23			129	31
146	28			143	36			147	33
140	25			120	18			125	28
141	21			136	31				
147	28								
159	31								
133	23								
143	28								
143	28	12 died		5 died		9 died		6 died	

APPENDIX II.—Regression statistics for all groups of fish. The regression coefficients *a*, *b*, and residual variance $s^2_{y.x}$ apply to logarithmic values of X and Y.

	n	$\bar{X}$	$\bar{Y}$	a	b	$s^2_{y.x}$
Control	25	143	26	−3.05	2.07	0.002201
C_1	13	137	27	−5.56	3.29	0.0007908
C_2	20	129	21	−7.08	3.83	0.002989
P_1	16	145	39	−3.12	2.20	0.003345
P_2	19	140	36	−2.70	1.97	0.002143
$C_1 + C_2$	33	132	23	−6.42	3.67	0.0024112
$P_1 + P_2$	35	142	37	−2.90	2.08	0.002387
San Pedro	. .	. . .	. .	−6.73	3.15	. . .

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NEW CALANOID COPEPODS OF *PONTELLA* DANA AND *LABIDOCERA* LUBBOCK WITH NOTES ON THE DISTRIBUTION OF THE GENERA IN THE GULF OF MEXICO

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NEW CALANOID COPEPODS OF *PONTELLA* DANA AND *LABIDOCERA* LUBBOCK WITH NOTES ON THE DISTRIBUTION OF THE GENERA IN THE GULF OF MEXICO

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Two previously undescribed species of *Pontella* Dana and one of *Labidocera* Lubbock were found during studies on an extensive collection of plankton samples from the Gulf of Mexico and a small number from the Cape Hatteras region. The plankton tows were made by the vessels ALASKA, ALBATROSS, and FISH HAWK, operating under the supervision of the U. S. Fish and Wildlife Service and its predecessors, the U. S. Commission of Fish and Fisheries and the U. S. Bureau of Fisheries, respectively. The ALBATROSS and the FISH HAWK were engaged in early oceanographic and fishery exploration cruises in the Gulf of Mexico and off Cape Hatteras, whereas the ALASKA recently conducted an oceanographic and biological survey of the Gulf of Mexico.

Notes on the distribution of other species of the two genera found in these collections are presented following the description of the new species. The cruise patterns of the ALASKA, which provided the majority of the records, are available in the Reports of the Texas A. and M. Research Foundation (1952, 1955).

FAMILY PONTELLIDAE

PONTELLA DANA, 1846

PONTELLA **MIMOCERAMI,**[1] sp. nov.

(Figures 1-13)

Localities, Material.—Key West (ALBATROSS, station number and collecting data not available, 1884, 55 males and females; sample taken between April 15-27 or May 7-10 in Key West Harbor according to Townsend's 1901 account of ship's activities; — FISH HAWK, station 7794, 26 December 1912, surface tow, one female). Coastal waters off Galveston, Texas (collected by writer in surface tows, 4 and 17 August 1954, two males). One mile southeast of Port Aransas (collected by Mr. R. J. Kemp, Texas Game and Fish Commission, in surface tow, 18 August 1956, one male). Lat. 34° 20′ N., long. 75° 50′ W., near Lookout Lightship off North Carolina (FISH HAWK, no station number, 3 September 1914, surface tow, one male, one female).

Measurements.—All measurements made from dorsal view; cephalothorax measured along midsagittal plane from anteriormost margin of forehead to posterior margin of intersegmental fold between

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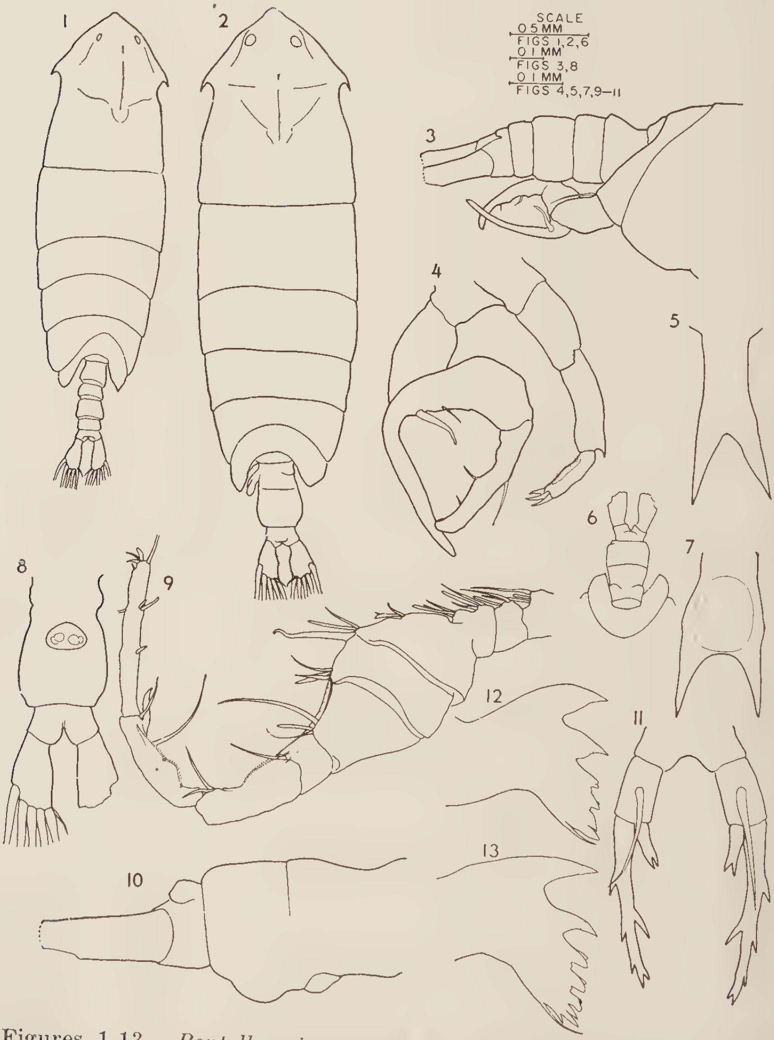
[1] The name *mimocerami* refers to the close relationship between the new species and *P. cerami* Scott.



Figures 1-13. *Pontella mimocerami*, sp. nov.: **1.** male, dorsal view; **2.** female, dorsal view; **3.** male abdomen, lateral view; **4.** male, fifth legs; **5.** female, rostrum; **6.** Female, abdomen, dorsal view; **7.** male, rostrum; **8.** female, abdomen, ventral view; **9.** male, geniculate antenna (less proximal segments); **10.** female, abdomen, lateral view; **11.** female, fifth legs; **12.** mandibular dentition.

Pontella tenuiremis Giesbrecht: **13.** mandibular dentition.

All figures drawn with aid of camera lucida; fig. 2 of holotype, remaining figures, except fig. 13, of paratypes.

thoracic segment V and genital segment; length of abdomen from anterior margin of genital segment to articulation between fifth innermost seta and right furcal ramus. Measurements made at 100x magnification with aid of ocular micrometer; specimen immersed in aqueous solution of 50% glycerine; slender glass rods used to support cephalothorax and abdomen in horizontal position. Measurements include total length (TL) and cephalothorax-abdomen length ratio (CAR).

1. *Adult female:* ALBATROSS; 10 specimens selected at random, TL range 3.18-3.63 mm, mean with standard error 3.29 ± .052 mm, standard deviation 0.156 mm, CAR range 3.5-4.2:1, mean 3.7:1. FISH HAWK, station 7794; TL 3.46 mm, CAR 3.9:1. FISH HAWK, Lookout Lightship; TL 3.40 mm, CAR 4.0:1.
2. *Adult male:* ALBATROSS; 10 specimens selected at random, TL range 2.70-3.18 mm, mean with standard error 2.95 ± .046 mm, standard deviation 0.138 mm, CAR range 2.9-3.5:1, mean 3.3:1. Galveston; two specimens, TL 2.98 mm, CAR 3.7:1; TL 2.46 mm, CAR 3.8:1. FISH HAWK, Lookout Lightship; TL 2.98 mm, CAR 3.6:1.

Diagnosis.—A population inhabiting coastal waters of the Gulf of Mexico and the temperate western North Atlantic Ocean in which the male is close to *P. cerami* Scott and the female is similar to *P. tenuiremis* Giesbrecht.

Adult female: Differs from *tenuiremis* chiefly in details of abdomen, fifth legs, and dentition of mandibular gnathal lobe.

Abdomen with genital segment partially separated from following segment by faint, incomplete suture (figs. 2, 6, 10). Anterior portion of genital segment with latero-dorsal swellings; swelling of left side enlarged in holotype, extending laterad in two lobiform processes (fig. 2); swelling of left side often a single reduced lobe similar to unilobed swelling on right side (fig. 6). Compound genital segment with greatest width posterior to suture, postero-ventral portion with moderate, rounded swelling (fig. 10). Anal segment narrower than preceding segment. Furcal rami normal, not attenuated, about one and one half times longer than maximum width (fig. 8).

Fifth legs (fig. 11) with exopodite bearing total of six spiniform processes, one medial, two terminal, three lateral; all excepting medial process reduced and somewhat equal in length; medial process about twice as long as others. Endopodite typically with bifid apex, bifurcation occasionally lacking; ramus not fused with basal segment 2.

Mandibular gnathal lobe with six teeth, fifth dorsalmost tooth monocuspidate (fig. 12); in *tenuiremis* gnathal lobe with eight teeth, fifth dorsalmost tooth bicuspidate (fig. 13).

Adult male: Differs from *cerami* with respect to thoracic segment V, geniculate antenna, and fifth legs.

Thoracic segment V with terminal portions in both dorsal and lateral views not truncate (figs. 1, 3); processes in dorsal view extending posteriad in triangular lappet somewhat rounded near apex, terminating in reduced spiniform apex.

Segment 17 of geniculate antenna with elongated ridge appressed to segment 16; proximal portion of ridge with low widely-spaced denticles, distal portion with closely-spaced spiniform denticles. Ridge of segment 18 with proximal denticles of uniform size. Proximal ridge of fusion segment 19-21 with single row of denticles. Segments 22-25 perfectly fused (fig. 9).

Chela of fifth legs (fig. 4) slightly different from that in *cerami* (vide Scott 1909: pl. 53, fig. 15); distal segment with blunt apex, irregular margins, and not arcate; proximal segment with small spine medial to large spine.

Types (cf. Localities, Materials).—All deposited in USNM. Female holotype, no. 99193, selected from material of ALBATROSS Key West station. Paratypes: nos. 99194-99196, 99203.

Further Description.—*Female:* rostrum lacking distinct lens (fig. 5); first antennae with 24 segments; second antennae with endopodal segment 1 separated from basal segment 2; remaining appendages as in genus. *Male:* rostral lens weakly to moderately defined; length of rostral processes about equal to diameter of lens (fig. 7).

Remarks.—Although the new species closely resembles the Indo-West Pacific species, *cerami,* this relationship is evident at present only in the male since the female of *cerami* is undescribed. However, the female of *mimocerami* appears to be similar to the following predominantly Indo-Pacific species of *Pontella,* as described by Giesbrecht (1892: pls. 24, 40): *tenuiremis; chierchiae* Giesbrecht; *fera* Dana.

The new species is distinguished in the male from the four species mentioned above by the following combined characteristics: (1) presence of an elongated, appressed, denticulated ridge on segment 17 of the geniculate antenna, the ridge completely overlapping the anterior margin of the preceding segment; (2) absence of lamellar or triangular processes extending from the proximal segment of the chela; (3) triangular non-truncated condition of the terminal portions of thoracic segment V. In the female it can be separated by (1) the single medial spiniform process on the exopodite of the fifth legs, (2) the pair of lateral swellings on the antero-dorsal portion of the genital segment, (3) the ventral swelling posterior to the genital orifice, and (4) the simple, almost symmetrical, terminal portions of segment V.

PONTELLA **POLYDACTYLA,**[2] sp. nov.

(Figures 14-24)

Localities, Materials.—Key West (ALBATROSS, same tow listed under preceding species, 16 males and females).

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[2] The name *polydactyla* refers to the many processes on the rami of the female's fifth legs.

Measurements.—All measurements made from right lateral view along imaginary straight line between limits; length of cephalothorax from anteriormost limit of forehead to posterior margin of intersegmental fold between thoracic segment V and genital segment; length of abdomen from antero-dorsal margin of genital segment to distalmost margin of right furcal ramus. Otherwise, as already given under preceding species.

1. *Adult female:* 10 specimens; TL range 3.43-4.03 mm, mean with standard error 3.73 ± .062 mm, standard deviation 0.18 mm, CAR range 3.3-3.9:1, mean 3.5:1.
2. *Adult male:* 6 specimens; TL 3.64 mm, CAR 3.5:1; TL 3.76 mm, CAR 3.6:1; TL 3.85 mm, CAR 3.2:1; TL 3.75 mm, CAR 3.6:1; TL 3.54 mm, CAR 3.8:1; TL 3.71 mm, CAR 3.3:1.

Diagnosis.—A robust species closely related to and strongly resembling *P. lobiancoi* (Canu) in dorsal view.

Adult female: Differs from *lobiancoi* primarily in details of thoracic segment V, abdomen, and fifth legs.

Posterior portions of thoracic segment V asymmetrical in dorsal view; right side triangular, left side truncate, each side with terminal styliform process extending posteriad beyond genital segment (figs. 14, 18).

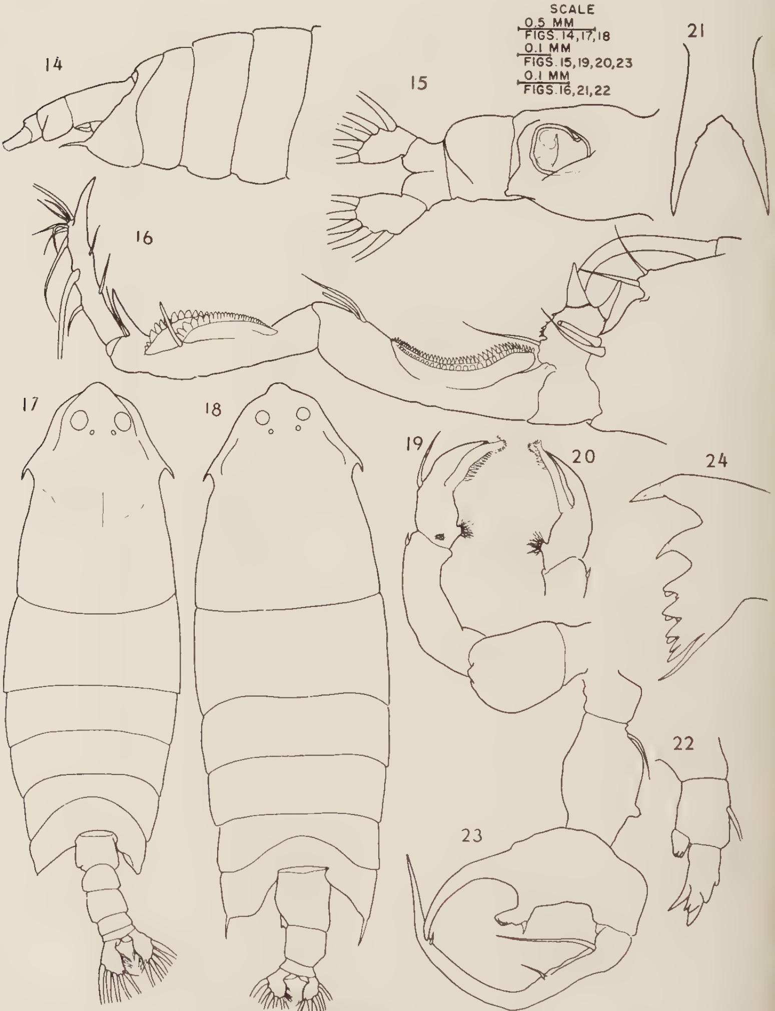
Abdomen with three visible segments as in *lobiancoi.* Genital segment with short ventral process posterior and to left of genital orifice (figs. 15, 18); segment lacking postero-dorsal swelling. Second abdominal segment asymmetrical, right postero-ventral portion bearing a conspicuous swelling (figs. 14, 15); segment's ventral surface smooth, lacking lobules and papillae. Furcal rami in dorsal view somewhat axiniform rather than rectangular.

Fifth legs with short thick rami; exopodite about as long as preceding segment, endopodite about as wide as long (fig. 22). Distal half of exopodite bearing six blunt spiniform processes, four distalmost overlapping. Endopodite terminating in two opposing pairs of short rounded processes.

Adult male: Differs from *lobiancoi* chiefly in details of geniculate antenna and fifth legs.

Geniculate antenna with segment 17 produced anteriad in robust irregular ridge; ridge armed with two, occasionally three, strong spines on proximal half, about six denticles on distal half. Ridge of segment 18 short, not reaching distal setae; denticles of ridge appear to be arranged in two rows, dorsal row with acuminate denticles, ventral row with lamelliform denticles. Two overlapping ridges of fusion segment 19-21 with robust denticles. Fusion segments 19-21 and 22-25 each terminating in a falcate spur (fig. 16).

Terminal segment of left fifth leg with acuminate apex flanked by two elongated lamellae; lamellae with unequal number of spinules on outer margin, unequal number of serrations on distal margin (figs. 19, 20). Chela of right fifth leg with distal segment extending be-



Figures 14-24. *Pontella polydactyla*, sp. nov.: **14.** female, lateral view (less cephalon, thoracic segment I); **15.** female, abdomen, ventral view; **16.** male, geniculate antenna (less proximal segments); **17.** male, dorsal view; **18.** female, dorsal view; **19.** male, left fifth leg, anterior view; **20.** terminal segment of male left fifth leg, posterior view; **21.** female, rostrum; **22.** female, fifth leg; **23.** male, right fifth leg, anterior view; **24.** mandibular dentition.

All figures drawn with aid of camera lucida; figs. 15 and 22 of holotype, remaining figures of paratypes.

yond falcate thumb of proximal segment; proximal segment with a somewhat digitiform process at midlength bearing one short medial spine (fig. 23).

Types (cf. Localities, Material).—All types deposited in USNM. Female holotype, no. 99213, selected from material of ALBATROSS, Key West; paratypes, nos. 99214, 99215.

Further Description.—Both sexes with rostrum lacking distinct lens (fig. 21). Forehead with pair of low rounded swellings just posteromediad to dorsal subcuticular lenses (figs. 17, 18). First antennae except male geniculate antenna with 24 segments; in female antennae extending to anterior margin of thoracic segment V. Second antennae with first segment of exopodite incompletely separated from second basal segment; in female exopodite shorter than first segment of endopodite. Second basal segment of leg 4 lacking distal seta. Male in lateral view with terminal portion of thoracic segment V bearing a short spiniform process on left side, lacking on right side. Remaining appendages as in genus.

Mated females with external lamelliform ornamentation, associated with spermatophore, enveloping genital segment; dorsal lamella with rectangular outline in dorsal view, covering dorsal surface of genital segment and overlapping right half of thoracic segment V; lateral lamellae fused with dorsal lamella, line of fusion sharp-edged; lateral lamellae extending mediad, overlapping ventral surface of genital segment.

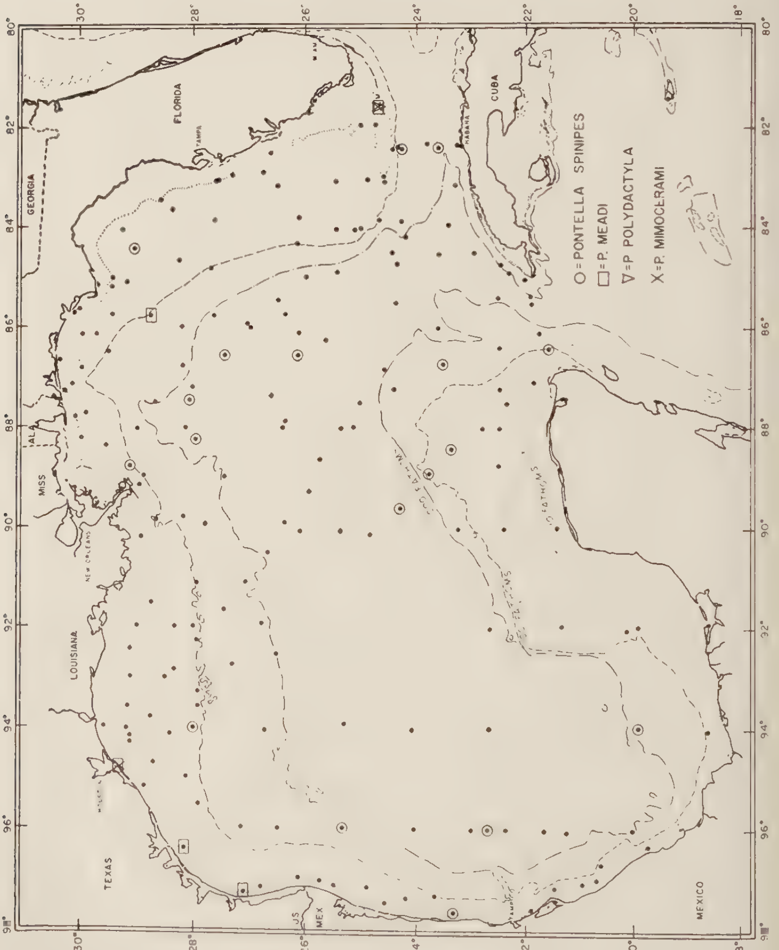
Remarks.—The new species is easily distinguished from all other known species of the genus in the female by the four-pronged endopodite of the fifth legs and the elongated styliform processes terminating thoracic segment V; in the male by the unusual form of the ridge and spines on segment 17 of the geniculate antenna and the pair of serrated lamellae on either side of the distal segment of the left fifth leg.

The similarity between *lobiancoi* and the new species compels reconsideration of the former's records from the Gulf of Mexico and the western Atlantic reported by Wilson (1932, 1942, 1950) and by King (1950). Except for these records, *lobiancoi* is known to occur only in the Mediterranean Sea and in Western European waters, Wimereux (Pas-de-Calais) being the type locality. It is noteworthy that this species was absent in the more than 200 samples collected by the ALASKA in the Gulf of Mexico. Considering the conspicuous, although superficial, resemblance between the two species and the usual occurrence of *lobiancoi* only in western European neritic waters, it seems best to regard Wilson's and King's records with reserve.

THE SPECIES OF *Pontella* IN THE GULF OF MEXICO

A qualitative analysis of more than 200 plankton samples collected by the ALASKA at surface stations scattered throughout the Gulf of Mexico revealed two known species of *Pontella, meadi* Wheeler and *spinipes* Giesbrecht, in addition to those described above. Geographical records of *Pontella* obtained during the present study are presented in Map 1.

P. meadi occurred at six widely scattered neritic localities over the northern shelf between the Florida Keys and Port Isabel. In addition, *P. pennata* Wilson was found together with *meadi* at all but one locality. The latter is not listed separately since there is considerable evidence (unpublished) that *pennata* is synonymous under *meadi,* a detailed account of this synonomy will be presented in a later paper. Previous records of *meadi* in the Gulf list the species from waters off western Florida (King 1950, Wilson 1950).



Map 1. Records of species of the genus *Pontella* collected by the M/V ALASKA in the Gulf of Mexico between April 1951-June 1953. Dots represent stations occupied by ALASKA.

P. spinipes appeared to be the most widespread species of the genus in the Gulf. It was found in 18 samples, occurring most frequently at stations made in slope and oceanic waters. Although there are no previously published Gulf records of *spinipes*, Jones (1952) has listed it from the Florida Straits region. According to T. E. Bowman (personal communication, 1955) the species has also been observed at Dry Tortugas and in the Caribbean Sea. Moreover, I have found *spinipes* together with *P. securifer* Brady in samples taken by the F. W. S. M V OREGON just south of eastern Cuba (unpublished).

Two other species of *Pontella* are purported to occur in the Gulf of Mexico. *P. atlantica* (Milne-Edwards) is questionably reported by Davis (1950), the determination based on a juvenile specimen taken off Rock Island, Florida. In addition, as already mentioned above, Wilson (1950) and King (1950) have listed *lobiancoi* from western Florida waters.

LABIDOCERA LUBBOCK, 1853

LABIDOCERA **MIRABILIS**,[3] sp. nov.

(Figures 25-37)

Localities. Material.—Florida Keys: lat. 24° 43′ N., long. 81° 57′ W. (ALASKA, cruise 11, station 14, 5 June 1953, 10 m. depth of plankton tow); Key West (ALBATROSS, same tow listed under two preceding species); Knight's Key (FISH HAWK, station 7788, 19 December 1912, depth ?); Dry Tortugas (FISH HAWK, station 7794, 24 December 1912, depth ?). Total of 55 specimens including males, females, and immature copepodites found in above samples.

Measurements.—All measurements made at 32x magnification from right lateral view, using methods described above under *Pontella polydactyla.*

1. *Adult female:* 11 specimens selected at random, TL range 2.54-2.95 mm, mean with standard error 2.80 ± .034 mm, standard deviation 0.109 mm, CAR range 3.5-4.2:1, mean 3.8:1.
2. *Adult male:* 18 specimens selected at random, TL range 2.21-2.54 mm, mean with standard error 2.37 ± .026 mm, standard deviation 0.111 mm, CAR range 4.4-5.5:1, mean 5.1:1.

Diagnosis.—A distinctive species of moderate size from the Florida Keys region that resembles *L. detruncata* (Dana).

Adult female: Differs from *detruncata* primarily in details of thoracic segment V, abdomen, and fifth legs.

Thoracic segment IV separated from segment V; terminal portions of V asymmetrical, right side extending farther laterad than left side and bearing larger spiniform process (fig. 28).

Abdomen with two segments. Genital segment asymmetrical, bear-

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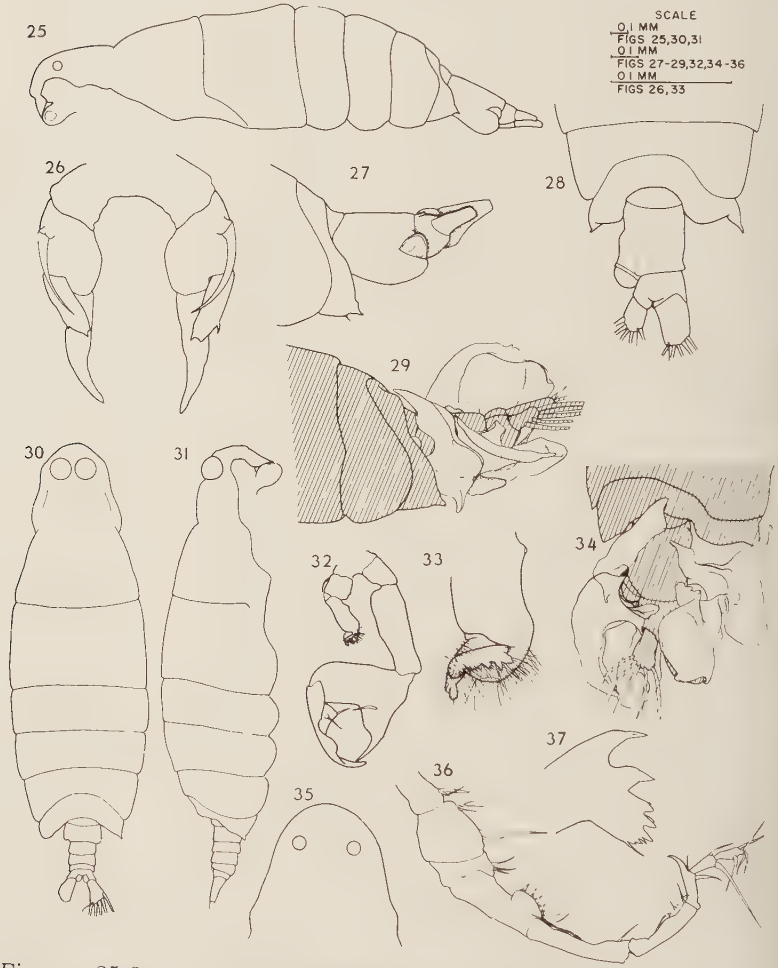
[3] The name *mirabilis* refers to the unique length relationship between the exopodite and endopodite of the female's fifth legs.

ing swelling on left side extending postero-laterad; genital orifice situated on postero-dorsal portion of swelling (figs. 27, 28). Anal segment not reduced. Furcal rami asymmetrical, right ramus longer



Figures 25-37. *Labidocera mirabilis,* sp. nov.: **25.** female, lateral view; **26.** female, fifth legs; **27.** female, abdomen, lateral view; **28.** female abdomen, dorsal view; **29.** female, abdomen with spermatophore and ornamentation, lateral view; **30.** male, dorsal view; **31.** male, lateral view; **32.** male, fifth legs; **33.** male, left fifth leg, terminal segment; **34.** female, abdomen with spermatophore and ornamentation, dorsal view; **35.** female, forehead, dorsal view; **36.** male, geniculate antenna (less proximal segments); **37.** mandibular dentition.

All figures drawn with aid of camera lucida; figs. 25, 26, 29, 34, 35 of holotype, remaining figures of paratypes.

and broader than left (fig. 28).

Fifth legs differ from those of all known species of *Labidocera;* endopodite longer than exopodite, ratio of former to latter about 1.8:1 (fig. 26). Exopodite with total of three short spiniform processes, one lateral, two apical. Endopodite moderately constricted midway in length, distal half curving mediad.

Adult male: Differs from *detruncata* in details of thoracic segment V, geniculate antenna, and fifth legs.

Thoracic segment V asymmetrical, right side with short spiniform process, left side rounded (figs. 30, 31).

Geniculate antenna (fig. 36) with ridge on segment 17 produced in robust ovate lobe bearing two marginal rows of five to eight denticles; denticles of dorsal row robust, those of ventral row minute. Ridge of segment 18 short, terminating at approximate midlength of segment; ridge armed with about 25 short blunt denticles. Fusion segment 19-21 with two slightly overlapping ridges, each ridge bearing blunt closely-spaced denticles. Segment 22 with distal falcate spur.

Left fifth leg with short ramus superficially unisegmental; short distal segment hirsute, partially fused to proximal segment and extending laterad (fig. 32); distal segment with posterior ridge and short digitiform apex offset laterad; ridge with multilobed distal margin (fig. 33). Chela of right leg with more elongated proximal segment than that in *detruncata:* distal segment with proximal triangular process bearing two spines and distal low lamella (fig. 32).

Types (cf. Localities, Material).—All deposited in USNM. Female holotype, no 99207, selected from material of ALASKA, cruise 11, station 14. Paratypes: nos. 99208-99212.

Further Description.—First antennae in female with 24 segments. Second antennae with basal segment 2 fused with segment 1 of endopodite. Remaining cephalic and thoracic appendages as in genus.

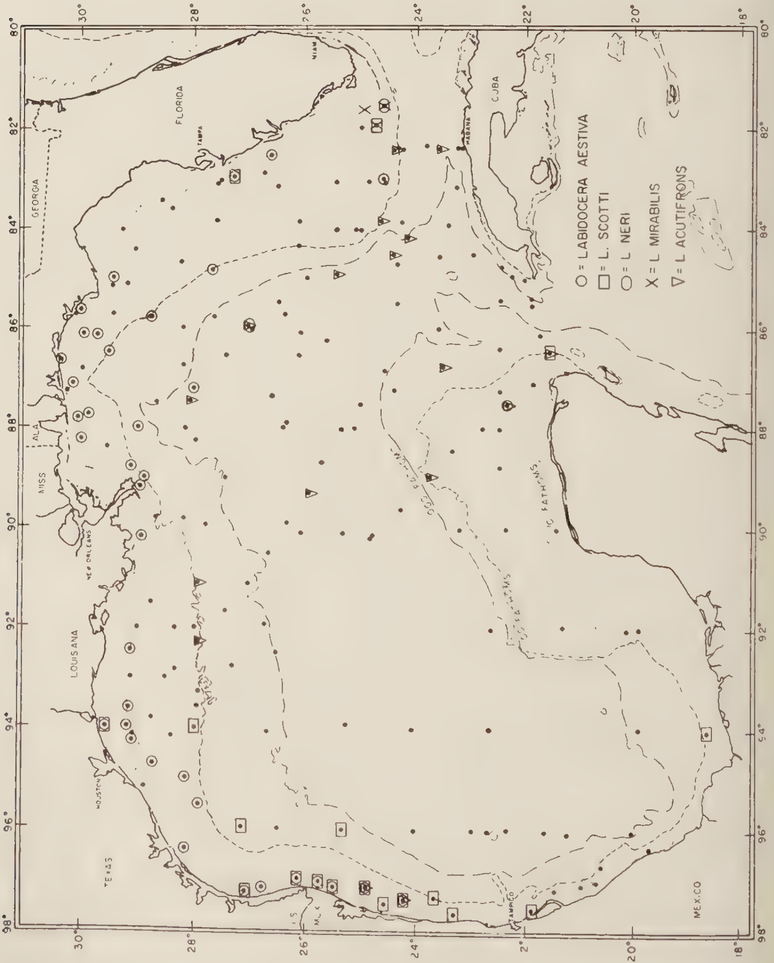
Mated females with abdomen obscured by complex lamelliform ornamentation associated with spermatophore (figs. 29, 34); ornamentation with somewhat rectangular basal plate ventral to genital segment and bearing a short ventral process at each corner; basal plate also supporting lateral lamellae which extend dorsad; those of right side larger, anterior one curving laterad, posterior one curving mediad; left side with two smaller lamellae, anterior one extending mediad, posterior one extending laterad.

Remarks.—The new species is readily distinguished from all other known species of the genus. The female is best characterized by the fifth legs, in which the endopodite is almost twice the length of the exopodite, and by the asymmetrical genital segment, bearing the genital orifice latero-dorsad on a left lateral swelling.

In the male the left fifth leg and the geniculate antenna possess excellent diagnostic features. The left fifth leg is superficially unisegmental with the terminal portion hirsute and turned laterad in a short truncate process. With respect to the geniculate antenna, segment 17 bears two rows of five-eight spines each, the dorsal spines being more than three times the size of the ventral spines, and segment 23 terminates in a robust falcate spur.

THE SPECIES OF *Labidocera* IN THE GULF OF MEXICO

In addition to *mirabilis,* four other species of the genus, *acutifrons* (Dana), *aestiva* Wheeler, *neri* (Krøyer), and *scotti* Giesbrecht, occur in the Gulf of Mexico. The local range of each of these species as determined from the ALASKA plankton collections is presented below (Map. 2).



Map 2. Records of the genus *Labidocera* collected by the M/V ALASKA in the Gulf of Mexico between April 1951-June 1953. Dots represent stations occupied by ALASKA.

L. acutifrons occurred at 13 oceanic localities east of long. 90° W., two oceanic localities south of Atchafalaya Bay, and two outer neritic localities off Laguna Madre. Included in this group are captures made in the mouth of the Yucatan Channel, in the vicinity of the Florida Keys, and off northern Cuba. Previous Gulf localities reported for the species are limited to the coastal waters off the southern half of Florida (King 1950).

L. aestiva, the most abundant species of Pontellidae in the collections, was confined almost exclusively to northern neritic waters between Florida and Laguna Madre. Numerically, the species was highly concentrated between Appalachicola Bay and the East Texas coast. Beyond these limits *aestiva* was taken in very small numbers, often only one or two specimens per standard tow.[4] A single specimen was also obtained from a tow made just off northern Yucatan. Both Davis (1950) and King (1950) have previously listed the species from the waters off western Florida.

L. neri was found at two localities, one in the vicinity of Key West and the other at about lat. 27° N., long. 86° W. The species has not been reported previously from the Gulf region.

L. scotti occurred at 17 ALASKA stations confined to or near neritic waters, including 14 coastal localities between the Lake Charles-Campeche area, one just off northeastern Yucatan, and two in coastal water off Florida, at Tampa and Key West, respectively. In addition, several records from Galveston, southern Florida, and the Florida Keys were established during the present study from collections by the ALBATROSS and the FISH HAWK as well as from material collected off Texas by the writer. The species was not found within the central portion of *aestiva's* range (Cape San Blas-Lake Charles). However, both species broadly overlap in the northeastern and northwestern sections of the Gulf. It is noteworthy that in the western overlap zone the number of *scotti* individuals per standard tow fell off gradually in the more northern samples. Conversely, *aestiva* showed a similar reduction in more southern tows with only single specimens per tow appearing in the Padre Island-Laguna Madre (Mexico) region.

Gradual displacement of *aestiva* by *scotti* also appears to occur proceeding south along the West Florida coast. The ALASKA material presents little evidence of a shift in the numbers of each species because of inadequate coverage of inshore areas in the region. However, Davis (1950) studying the plankton of the entire coast of western and southern Florida found *scotti* to be the most abundant and widespread species of *Labidocera* along the west coast. Around the southern tip of Florida, particularly within Biscayne Bay, extensive sampling both seasonally and geographically by two investigators (Davis 1950, Woodmansee 1949) have firmly established the year-round presence of *scotti.* In contrast, *aestiva* was not found during these studies, nor did it occur in the inshore collections made in Florida Bay by Davis and Williams (1950).

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[4] A 30 minute horizontal tow at 1 meter depth with one half meter net, No. 10 mesh.

At first glance, King's (1950) plankton survey of the entire west coast of Florida, in which *aestiva* and *acutifrons* are the only species of *Labidocera* listed, would appear to contradict Davis' results. However, *scotti* is not described or mentioned in the literature of those copepod specialists referred to by King as his source for specific identifications. Therefore, it is probable that King was unfamiliar with *scotti* and possibly confused it with *aestiva.*

It is interesting that the distributional patterns outlined by the available data on *aestiva* and *scotti* in the Gulf of Mexico conform closely with the two principle temperature zones of the region. Ekman (1953) and Hedgpeth (1953) have noted that with the exception of the southern half of both Texas and Florida the neritic waters off the Gulf states are characterized by warm temperature conditions (> 10° - ca. 25° C). For example, within the region in which *aestiva* predominates, the molluscan fauna is predominantly Carolinian (Rehder 1954) and *Crassostrea virginica* (Gmelin) occurs as a community dominant (Ekman 1953). The remaining neritic waters of the Gulf, with *scotti* the predominant species of the genus, apparently transcend from subtropical to tropical conditions (ca. 20° - > 25° C), culminating in the presence of coral reefs in the Tampico, Vera Cruz, Campeche, and Yucantan areas (Walton Smith 1954). Thus, in the Gulf the two species appear to be planktonic indicators of the two respective coastal water zones. Since they also fulfill adequately the physical requirements for planktonic indicator species (large size, singular appearance, high relative abundance, etc.), they should be subjected to more detailed study.

Apart from the Gulf, temperatures characteristic of the known range of each species are remarkably similar to conditions within the local Gulf range. *L. aestiva* is a well established inhabitant of temperate coastal waters between northern Florida and the Gulf of St. Lawrence (type locality: Woods Hole, Massachusetts). It has also been recorded from Brazilian coastal waters (Carvalho 1945, 1952; Oliveira 1946), but the existence of three other species in this area (*fluviatilus* Dahl, *darwini* Lubbock, *braziliense* Farran) that are very similar to *aestiva* casts some doubt on the validity of these reports. In contrast, *scotti* is known only from the tropical or near-tropical waters off the African west coast (type locality: Gulf of Guinea).

In summary, at least five species of the genus *Labidocera* are represented in the Gulf of Mexico. Regarding the three most abundant and widespread of these species, each appears to predominate in a different environmental area: *acutifrons* is found throughout the oceanic region, *aestiva* occurs along the northern temperate coastal area, and *scotti* is representative of the tropical or near-tropical coastal area.

Although, admittedly, data on *Pontella* in the Gulf of Mexico are sparse, the available information suggests that, as in *Labidocera,* the species tend to be environmentally separated as follows: *meadi*—warm-temperate neritic, *mimocerami*—tropical neritic, and *spinipes*—tropical oceanic. The remaining species, *P. polydactyla, L. neri* and *L. mirabilis,* appear to be infrequent transients in the easternmost portions of the Gulf region.

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ABSTRACT

Descriptions are presented for three new calanoid copepods taken in the Gulf of Mexico during plankton collecting operations of the U. S. Fish and Wildlife Service: *Pontella mimocerami*, n. sp., is related to *P. cerami* Scott; *P. polydactyla*, n. sp., is close to *P. lobiancoi* (Canu); *Labodocera mirabilis*, n. sp., resembles *L. detruncata* (Dana).

Records of previously known species of *Pontella* Dana and *Labidocera* Lubbock that appeared in the numerous plankton samples under consideration are charted. Their distributional patterns in the Gulf of Mexico are discussed. From the available evidence the more abundant and widespread of the species within each genus tend to be separated environmentally from one another. In *Labidocera*, *aestiva* Wheeler is temperate-neritic, *scotti* Giesbrecht is tropical-neritic, and *acutifrons* (Dana) is tropical-oceanic. In *Pontella*, *meadi* Wheeler is temperate-neritic, *mimocerami* is tropical-neritic, and *spinipes* Giesbrecht is tropical-oceanic. The remaining species, *Pontella polydactyla*, *Labidocera neri* (Krøyer), and *L. mirabilis* appear to be transients in the easternmost portions of the Gulf region.

Reprinted from SCIENCE, June 14, 1957, Vol. 125, No. 3259, page 1194.

Marine Fungus Infecting Eggs and Embryos of Urosalpinx cinerea

This paper reports a fungus infestation of ova within the egg cases of the marine gastropod *Urosalpinx cinerea* (Say), the common oyster drill (*1*). This observation is important since it offers a possible biological control measure for this snail, which is one of the most destructive predators of young oysters. *Urosalpinx cinerea* is currently being studied by the U.S. Fish and Wildlife Service and other groups in an effort to develop methods for controlling its predation. This fungus is one of the few natural controlling factors known for this gastropod.

Fungus infestation in drill egg cases was first observed in cases taken from our outdoor tidal tanks, in which oyster drills are kept for laboratory study. Figure 1 shows an egg case, with its outer membrane removed, containing four dense masses which were once healthy ova and now are infected with fungus growth.

This fungus was isolated from the infested cases and was cultured by H. S. Vishniac (*2*), who thinks that it is a new form resembling *Sirolpidium zoophthorum*. She believes that this fungus belongs to the order Lagenidaiales and resembles the Sirolpidiaceae but lacks the septa which characterize this family, as defined by Sparrow (*3*). Because the fungus also resembles *Plectospira dubia* (Atkins), a marine fungus capable of infecting crustacean eggs, a pure culture of our fungus was sent to D. Atkins (*4*). She was successful in infecting the eggs of the oyster crab, *Pinnotheres*, with our isolate but is of the opinion that it is not the same as *P. dubia*.

Preliminary experiments conducted with a culture isolate demonstrated that this fungus will infect ova within the egg cases of *U. cinerea* in sterilized sea water, at 20°C, with a salinity of 21 parts per thousand. Moreover, ova do not have to be moribund for the infestation to develop. In one experiment, a flask containing 200 ml of sterile sea water and 20 washed egg cases containing ova and early gastrulae was inoculated with 3 ml of the cultured isolate. One hundred-percent infection occurred within 24 days, although the controls had developed from ova to protoconchs with no infestation.

In a similar experiment, 12 egg cases, of which four contained ova, four, veliger larvae, and four, protoconchs, were used. At the end of 28 days the four egg cases which initially contained protoconchs had released them; the veliger larvae developed to protoconchs; but the egg cases that contained ova were infected and did not develop. Normal development, with no infections, occurred in the control.

In early experiments, in which infected egg cases were used as an inoculum, only egg cases that contained ova through veliger stages were infected, not the older egg cases that contained protoconchs. Hence, infection appears to be confined to the ova and early developing stages and, in this respect, resembles the infecting behavior of *P. dubia* on crustacean eggs, inasmuch as *P. dubia* is likewise less pathogenic for the prezoeal and zoeal stages than it is in the early stages of the egg development (*5*).

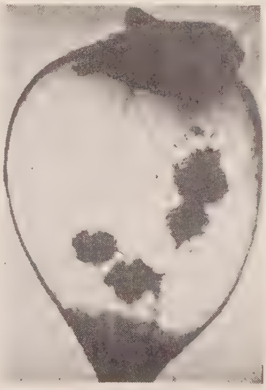

Fig. 1. An egg case of *Urosalpinx cinerea* with its outer membrane removed to show four dense masses of fungus-infested ova (× 10).

Biotic control of the drill by using a trematode parasite which causes castration in snails has been suggested by Cole (*6*). The only other known biotic factor which might be considered as a means of control is a tube-dwelling amphipod, which was found to form mud tubes in drill egg cases and presumably destroys the ova of the drills on the West Coast (*6*). Hence, the fungus infestation here described presents another biotic factor which may be considered for control of *U. cinerea*. However, the practicability of control by the use of a fungus is doubtful, since any control measures in the field would demand the creation of environmental conditions conducive to infestation and dissemination. On the other hand, if this fungus can be carried and spread by the drills themselves, it may offer a specific, natural infecting agent capable of reducing efficiently the population density of the oyster drill.

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References and Notes

1. I wish to thank V. L. Loosanoff, for his assistance in pursuing this problem, and C. A. Nomejko, for preparing the photomicrograph. I also wish to thank H. S. Vishniac, for preparing the fungus isolate, and D. Atkins, for allowing me to refer to her correspondence with Vishniac.
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6. M. R. Carriker, *Special Science Rept. Fisheries* No. 148 (1955).

4 April 1957

All technical papers and comments on them are published in this section. Manuscripts should be typed double-spaced and be submitted in duplicate. In length, they should be limited to the equivalent of 1200 words; this includes the space occupied by illustrative or tabular material, references and notes, and the author(s)' name(s) and affiliation(s). Illustrative material should be limited to one table *or* one figure. All explanatory notes, including acknowledgments and authorization for publication, and literature references are to be numbered consecutively, keyed into the text proper, and placed at the end of the article under the heading "References and Notes." For fuller details see "Suggestions to Contributors" in *Science* 125, 16 (4 Jan. 1957).

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NUTRITION OF SALMONOID FISHES

III. WATER-SOLUBLE VITAMIN REQUIREMENTS OF CHINOOK SALMON [1]

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(Received for publication December 28, 1956)

INTRODUCTION

Early attempts to investigate the vitamin requirements of fish were hampered by the lack of a vitamin-test diet in which the growth factors could be adequately controlled. McCay and Dilley ('27) postulated the requirement of trout for a factor H present in fresh meats. General requirements for certain vitamins were recognized (McCay, Bing and Dilley, '27; Titcomb et al., '29; Tunison et al., '42; Wolf, '42; Woodbury, '42) and under certain conditions anemia could be prevented by the administration of xanthopterin (Simmons and Norris, '41) or some B vitamin combinations (Tunison et al., '43). McLaren et al. ('47b) published a diet consisting of commercial casein, starch, fish liver oils, crab meal, minerals and vitamins which would maintain rainbow trout *(Salmo gairdneri)* for a growing period of 20 weeks. Feeding trials with chinook salmon *(Oncorhynchus tshawytscha)* and extended feeding trials with this diet and rainbow trout were unsatisfactory (Rucker, Johnson and Kaydas, '52). Wolf ('51) observed some vitamin deficiency syndromes in rainbow trout fed a test diet of commercial casein, potato starch, gelatin, minerals, hydrogenated cottonseed oil, cod liver oil, and crystalline vitamins. The requirements of rainbow trout

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[1] Presented at the meetings of the American Institute of Nutrition, Atlantic City, New Jersey, April, 1956.

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for pantothenic acid, inositol, and folic acid were reported but the niacin, biotin, ascorbic acid, vitamin B_{12}, alpha-tocopherol and vitamin K-deficient lots of fish failed to develop observable deficiency syndromes (Wolf, '51). Using vitamin-test casein, previously reported unsatisfactory for trout feeding studies (Wolf, '51), changing the fat and carbohydrate components, and slightly altering the mineral and crystalline vitamin supplements, a vitamin-test diet was formulated for feeding trials with chinook salmon as the experimental animal.

EXPERIMENTAL

Experiment 1. Complete diets. The complete vitamin-test diet was formulated from the materials listed in table 1. Prior to mixing the diet, the crystalline vitamin supplement, the amino acid supplement and the alpha-cellulose flour were mixed for two hours in a ball mill and then stored at 5 to 10° C., until used. To insure more accurate and reproducible weights, sufficient alpha-cellulose flour, amino acids and vitamins for at least 4 kg of diet were mixed at one time. The mineral mixture was also ground for two hours in a ball mill and stored in a tight container until needed.

To prepare 400 gm of mixed diet containing 25% solids and 75% water, 15 gm of purified gelatin were added to 300 ml of water and heated on a steam bath until the temperature rose to 60 to 70°C. After the gelatin became liquefied, the container was removed from the steam bath, placed in a mechanical mixer and stirred at medium speed with a dough hook until the temperature had dropped to 40 to 50°C. Then 54 gm vitamin test casein, 9 gm purified corn oil, 8 gm white dextrin and 4 gm mineral mixture were added and thoroughly blended. Finally, the alpha-cellulose flour containing the vitamin mixture and the amino acid supplement was added and stirred until a homogeneous mass was obtained (30 to 35°C.). For convenience in future feeding, the mixture was poured into ice cube containers, hardened in a refrigerator at 10°C., and stored in screw-top glass jars at 5 to 10°C. until used.

TABLE 1

Composition of the vitamin-test diet for chinook salmon

MAIN MIXTURE	PARTS	MINERAL MIXTURE	AMOUNT	VITAMIN SUPPLEMENT	AMOUNT [1]
					mg
Vitamin-free casein	54	U.S.P. XII Salt Mixture No. 2	100 gm	Thiamine-hydrochloride	6
Gelatin, purified	15	Aluminum chloride	18 mg	Riboflavin	20
Corn oil, purified	9	Zinc sulfate	357 mg	Pyridoxine hydrochloride	4
White dextrin	8	Cuprous chloride	11 mg	Nicotinic acid	80
Alpha-cellulose flour	9	Manganous sulfate	80 mg	Calcium pantothenate	28
Mineral mixture	4	Potassium iodide	17 mg	Inositol	400
DL-Methionine	1	Colabtous chloride	105 mg	Biotin	0.6
L-Tryptophan	0.5			Folic acid	1.5
Crystalline vitamin supplement				p-Aminobenzoic acid	40
				Choline chloride	800
				Ascorbic acid	200
				Alpha-tocopherol	40
				Menadione	4
				Beta-carotene	1.2
				Activated 7-dehydrocholesterol	0.0045
				Crystalline vitamin B_{12} [2]	0.009

[1] These amounts of individual vitamins were added per 100 gm of the main mixture.

[2] Merck.

The resulting diet was a firm homogeneous mass which could be fed easily through a food ricer, sieve or grater. Correct particle size was adjusted by the size of the grater or ricer used in feeding, and as the fish developed, the consistency of the diet was altered to 30% solids and 70% water. Similarly, the density of the diet was varied from a floating diet for initial feeding to a slowly sinking diet for larger fish by adjusting the speed of the mechanical mixer during the cooling and mixing period.

Four groups of 1,000 yolk-sac chinook salmon fry, a representative random sample from one day's egg take at the State of Washington Department of Fisheries' Soos Creek Hatchery, were placed in screened troughs supplied with dechlorinated Seattle city water and taught to feed on finely ground fresh beef liver. After three weeks, all the yolk-sacs had been absorbed and the lots of fish were feeding actively on the liver diet. Two 1,000 fish lots were then taught to feed on the complete vitamin-test diet and the other two were continued on beef liver. In general, the techniques used in the hatchery followed closely the techniques developed by the Fish and Wildlife Service for conducting feeding trials (Burrows, Palmer and Robinson, '51). Bi-monthly growth measurements, daily mortalities and daily food consumption were recorded on all groups for a feeding period of 18 weeks.

After the fry were actively feeding, only as much diet as the fish would eat completely within one minute after presentation was grated into the upper one-third of each trough. The fish were fed three times daily, 6 days per week, with no diet fed on Sundays. As the fish developed in size, the water and air content of the ration was reduced, and after the fish were an average size of one gram, a slowly sinking diet containing 30% solids and 70% water was prepared twice weekly for the remainder of the experiment. After 6 weeks of feeding, all lots were reduced to 500 fish per trough to prevent overcrowding. Freshly ground beef liver, obtained from the School of Fisheries production diet, was fed through a ricer or sieve to the paired control lots at the same level and frequency as the test diet lots. The growth-mortality curves and the food consumption were plotted as shown in figure 1 and table 2.

Experiment 2. Vitamin-deficient diets. The following year, a different group of chinook salmon fry from a different natural water supply was used to check the adequacy of the complete test diet on other runs of chinook salmon and to develop specific vitamin deficiency syndromes by deleting one water-soluble vitamin at a time from the complete vitamin mixture in the diet. Consequently 13,000 fry from three summer-run chinook salmon females were obtained from the U. S. Fish and Wildlife Service Entiat River Salmon Cultural Station, transported to the laboratory in a tank truck, acclimated to the experimental hatchery water supply and taught to feed on the complete test diet. Since these fry were actively feeding when obtained and had been on a production diet containing large amounts of liver and other vitamin rich animal tissues, it was decided to hold the fry on the test diet without the vitamin supplement at least three weeks before initiating the deficiency diet tests in an attempt to decrease as much as possible the stored biological materials in their systems. After three weeks the entire lot was weighed, combined in one trough, crowded into the head end of the trough, and representative random samples of 500 fish were

TABLE 2

Growth, mortality and food consumption of chinook salmon

RATION	NO. FISH	INITIAL WEIGHT	FINAL WEIGHT	PER CENT GAIN	PER CENT MORTALITY[1]	FOOD FED[2]	FOOD VERSION CON- RATIO	WEEKS OF FEEDING
		gm	*gm*			*gm*		
Test diet	1000	0.49	5.31	984	5.58	11080	4.3	18
Test diet	1000	0.49	5.49	1020	8.37	11080	4.5	18
Liver	1000	0.49	6.97	1322	5.87	19190	4.0	18
Liver	1000	0.49	6.77	1280	7.07	19190	4.3	18

[1] Mortality not attributable to Columnaris disease.

[2] Calculated on the basis of 25% solids diet.

hand counted and weighed to within one gram on a solution balance. Each group of 500 fry weighed 745 ± 2 gm, substantiating the accuracy of the sampling technique used.

Throughout the remainder of the experiment, all weighings were conducted by one individual (JEH) and, by periodically

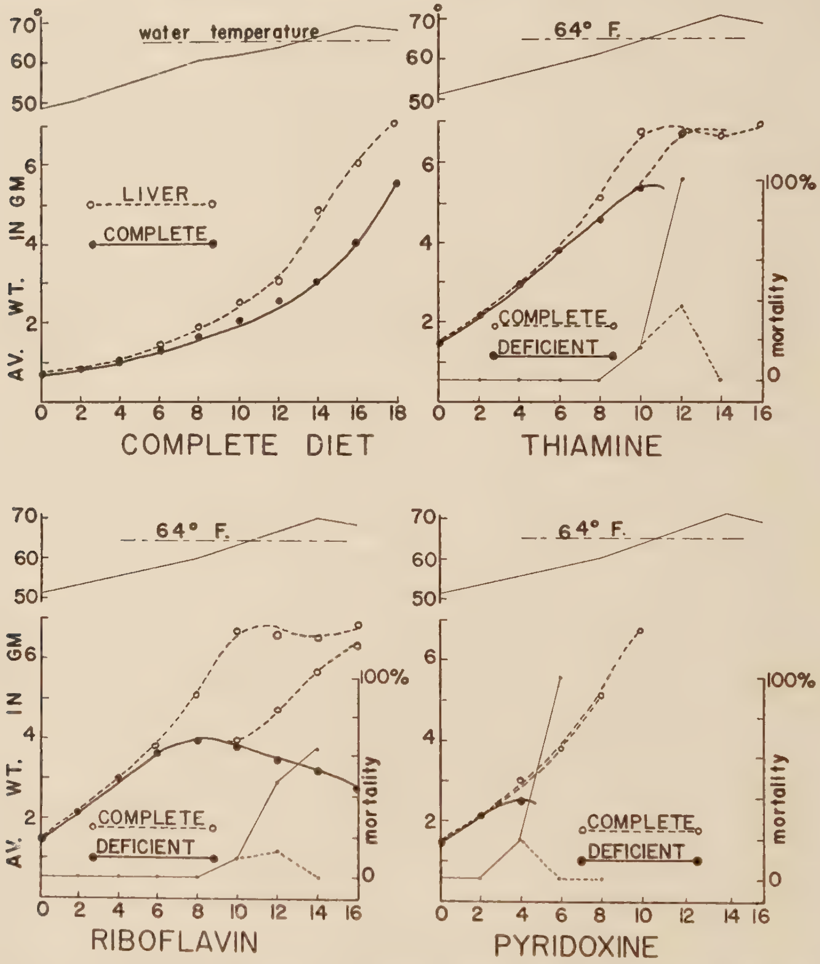

Fig. 1 Growth and mortality of chinook salmon fed complete diets and diets deficient in thiamine, riboflavin or pyridoxine. *Upper* curves, average water temperature; *central* curves, growth; *lower* curves, bi-weekly mortality percentage of the deficient group. Junction points in growth and mortality curves represent division of the deficient groups into two sublots after the deficiency syndromes became apparent in a large portion of the population.

conducting a series of weights on each group, were shown to be reproducible to within 1%. The entire population of each trough was weighed prior to the morning feeding by removing the entire population in one net, draining off the excess water over a 10 second period, wiping the bottom of the net clear of adhering water and transferring the fish to a tared container with sufficient water to maintain the fish during the weighing period. After weighing, the fish were immediately returned to their trough and in one-half hour were fed.

Individual brushes and food graters were marked at each trough to minimize transfer of nutrients or pathogens when cleaning or feeding. Each diet jar was numbered and labelled to correspond with the number and label on each trough to prevent inadvertent erroneous feeding. All troughs were cleaned daily to prevent the accumulation of feces and the growth of bacterial and fungus matter. Food was grated into the upper one-third of each hatchery trough three times daily throughout the experimental feeding period. Only as much food was fed as the fish would eat within one minute after presentation.

Daily mortalities were removed and recorded as soon as observed. Dead or obviously moribund fish were examined closely for the presence of fish pathogens and for indications of the various vitamin deficiency syndromes listed by McLaren et al. ('47a), Tunison et al. ('44), and Phillips et al. ('45, '47, '49, '50) for trout.

Since only 14 experimental feeding troughs were available in the hatchery for these vitamin deficiency studies, the experiments could not be conducted in duplicate. This disadvantage was not serious, however, in view of the feeding results and the techniques used. It was obviously significant when over half the population died exhibiting various specific vitamin deficiency syndromes and the other portion of the population in the trough recovered after replacement of the missing vitamin in the diet. For further evidence on the significance of the mortalities, the mortality percentage of each group was examined by the Chi-square Test. Similarly, the difference in growth rates between the controls and those on deficient diets were examined for significance at the 95% confidence level by the Student t_N Test at the end of 10, 12, and 14 weeks of feeding respectively.

The general approach to developing the various vitamin deficiencies included feeding each group of fish in the 12 troughs one water-soluble vitamin-deficient diet and allowing the deficiency syndromes to develop until 20% of the original population of 500 fish had died. The remaining population was divided in half, weighed to confirm random division, the lower one-half of the trough fed the complete vitamin-test diet and the upper one-half allowed to continue on the deficient diet until complete elimination of that population. For purposes of comparison, two troughs were fed the complete vitamin-test diet throughout the experimental-feeding period as controls. Two parts of cod liver oil were substituted for two parts corn oil and the crystalline beta-carotene and activated 7-dehydrocholesterol were deleted from the crystalline vitamin supplement for the deficiency-feeding trials.

Assays of the levels of residual vitamin activity present in the vitamin-deficient diets were completed on the solid ingredients of the diet and the diet as fed (25% solids and 75% water). Duplicate samples were assayed at 5 levels and compared with standards in triplicate at 10 levels in conformance with standard microbiological assay techniques. All organisms used in the microbiological assays were fresh cultures obtained directly from the American Type Culture Collections, Washington, D. C. Thiamine was run by the method of Sarett and Cheldelin ('44) using *L. fermenti* 36; riboflavin, nicotinic acid and folic acid by the method of Roberts and Snell ('46) using *S. faecalis* R; pantothenic acid by the hydrolysis method of Novelli and Schmetz ('51) and the assay method of Skeggs and Wright ('44) using *L. arabinosis* 17–5; inositol by the method of Sawyer ('51) using *Kloeckera brevis;* biotin by the method of Wright and Skeggs ('44) using *L. arabinosis* 17–5; para-aminobenzoic acid by the method of Lewis ('42) using *L. arabinosis* 17–5; and choline by the method of Horowitz and Beadle ('43) using *Neurospora crassa* "cholineless." Vitamin B_{12} was assayed by Miss Neva Kerrick in the microbiological assay laboratories of the Fish and Wildlife Service Branch of Commercial Fisheries in Seattle by the method of Hoffman et al. ('49) using *L. leichmannii.* Ascorbic acid was determined by the 2–4 dinitrophenylhydrazine method of Roe and Oesterling ('44). Details of the results were tabulated in table 3.

Experiment 3. Deficient diets at constant temperatures. Experiment 2 was repeated with another lot of fish at a different laboratory using a constant temperature water supply (58°F.). The diets deficient in one water-soluble vitamin were fed to paired lots of salmon fry from a third source of fish (Columbia River fall run chinook salmon) at the Hagerman, Idaho Nutrition Laboratory. Feeding techniques and biological observations during the 20-week feeding period were identical with the previous experiment.

Since these groups of deficient fish were used as negative control lots in a quantitative experiment,[2] replacing the missing vitamin for recovery experiments in depleted groups was not possible. Therefore, these groups were continued beyond the point where the majority of the population died from deficiency syndromes.

RESULTS AND DISCUSSION

Experiment 1. After 16 weeks on the experimental diets, the water temperature rose to above 65°F. and a severe epizootic of Columnaris *(Chondrococcus columnaris)* occurred, forcing termination of the feeding trials at the end of the 18-week period. At the end of the experiment, total blood cell counts, hemoglobin determinations, microscopic examinations of gill filaments and post-mortem examinations of the liver, spleen, kidney, stomach, pyloric caeca and intestines were made on 20 fish from each lot. No abnormalities in mortality, food consumption, total blood cell counts, hemoglobin determinations, gill filament examinations, or post-mortem examinations of the internal and external organs were observed in any fish from any of the 4 experimental lots. During the last two weeks of the experiment, all dead fish were examined for Columnaris and in each experimental lot groups of *Chrondococcus columnaris* were observed. Particular emphasis was placed on observing any of the vitamin deficiency syndromes reported by McLaren et al., ('47b) in rainbow trout, but by the end of the experiment no recognizable vitamin deficiency syndrome could be detected in any salmon from either of the paired groups of fish.

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[2] Details of quantitative experiments to be published later.

During the entire feeding period the lots of fish on both the liver and the complete vitamin-test diet exhibited a healthy appetite and would consume all food offered within the feeding period. No indications of food refusal were noted, and as long as the ration presented did not exceed the appetite, little wastage was observed. Some of the nutrients were obviously lost due to leaching in the water before the salmon could consume them, but this effect was not excessive in view of the food consumption and growth results summarized in table 2.

Since the epizootic of Columnaris disease prevented accurate calculations of growth rates, food consumption and normal mortalities during the last two weeks of the feeding trials, the experiment was terminated after 18 weeks of feeding. Even though the growth rates indicated that the fish on the test diet would approach or exceed that of the groups on the liver diet within 20 to 22 weeks, it was doubtful whether these fish could have been held in troughs for an additional two weeks because of the "space factor" effect described by Johnson and Gastineau ('52) or because of the migratory urge which appears in groups of chinook salmon held in troughs when the average weights of the individual fish exceed 7 to 9 gm.

The differences of the means of each group of points forming the two growth curves in figure 1 were examined by the

Student t_N Test and were found acceptable except those points representing the 14th and 16th weeks of feeding. These two sets of points were rejected by this test and must therefore be regarded as significant differences at the 95% confidence level.

Throughout the experimental feeding period the experimental animals gave every indication of being healthy. None of the tests indicated that they were abnormal in any respect.

TABLE 3

Vitamin assays of deficient diets for chinook salmon[1]

DEFICIENT DIET	SAMPLE	VITAMIN MIX	DIET[2]	DETECTABLE	METHOD USED
	gm	*μg/gm*	*μg/gm*	*μg/gm*	
Thiamine	10	0.25	0.1	0.01	MBA[3]
Riboflavin	10	2.5	0.22	0.1	MBA
Pyridoxine	10	NDA[4]	0.07	0.01	MBA
Nicotinic acid	10	0.6	0.7	0.1	MBA
Pantothenic	10	1.9	0.24	0.1	MBA
Inositol	10	20.0	17.0	5.0	MBA
Biotin	10	0.0165	0.0053	0.002	MBA
Folic acid	10	0.75	5.9	0.5	MBA
p-Aminobenzoic	10	NDA	NDA	0.1	MBA
Choline	10	7.0	4.5	1.0	MBA
Ascorbic acid	100	3.5	1.0	0.5	Chem
Vitamin B_{12}	10	NDA	0.005	0.0001	MBA

[1] Mean values reported of duplicate samples each of vitamin mixture and diet.

[2] Calculated on basis of diet containing 25% solids and 75% water.

[3] Microbiological assay method.

[4] No detectable amount.

Although the growth rates for the fish on the test diets were below those on the liver diet, all examinations revealed healthy fish without the appearance of any recognizable vitamin deficiency syndrome. Total blood cell counts made by caudal peduncle amputation, blotting, dilution in red blood cell hemacytometers with gentian violet in saline solution, and counting under a microscope revealed a normal blood cell count of all fish on all diets between 1,250,000 and 1,500,000 rbc/mm^3. Hemoglobin determinations made on Talquist-Adams paper varied between 10.9 and 14.1 gm/100 ml blood for all fish examined. Microscopic examinations of gill filaments and post mortem examinations of livers, spleen, kidneys, stomachs, pyloric caeca and intestines showed the absence of any recognizable pathological condition. The abdominal fat was slightly excessive in those fish on the liver diet, but this was not considered significant in view of the reported characteristics of body fat in fish (Norris and Donaldson, '40). With the exception of the Columnaris infection which grew to epizootic proportions during the last two weeks on the diet, no pathological condition or deficiency syndrome could be defined.

Experiment 2. The deficiency syndromes observed and the growth curves of each vitamin-deficient lot of salmon are shown in table 4 and figures 1–3.

An apparent decrease in dietary intake was observed in the 12th week of the experiment when the water temperature rose to over 65°F. Near the end of the feeding period, the temperature decreased with a consequent increase in appetite and growth in the lots of fish fed the complete diet. A more constant temperature of the water supply within the range of 50 to 60°F. probably would have strengthened the interpretation of the feeding trials.

Since tryptophan was included in the supplement to the protein component, it was to be expected that the nicotinic acid-deficient group of fish would be delayed in exhibiting the deficiency syndrome. Fortunately, after 13 weeks of feeding, the mortality in this lot rose to 20% of the original population and the group could be split. During the last three weeks of feeding the deficiency syndromes became more apparent and the mortality continued to increase in the deficient lot. Continuing this experiment further probably could have shown a greater divergence between the recovery and deficient groups.

The choline-deficient group exhibited little mortality until the 14th week of feeding, but the growth of the fish was very slow. Probably the methionine content of the diet acted as a partial methyl donor and tended to spare the requirement for choline.

TABLE 4

Signs of avitaminosis in chinook salmon fed vitamin-deficient diets

VITAMIN DEFICIENCY	CHINOOK SALMON	OTHER ANIMALS [1,2]
Thiamine	Poor appetite; muscle atrophy; convulsions prior to death; instability and loss of equilibrium.	Poor appetite; muscle atrophy; convulsions in most acute stage; generalized edema; instability and loss of equilibrium; brain lesions; degeneration of peripheral nerve fibers; impaired carbohydrate metabolism.
Riboflavin	Corneal vascularization; cloudy lens, hemorrhagic eyes; photophobia; dim vision; incoordination; abnormal pigmentation of iris; striated constrictions of abdominal wall; dark coloration; poor appetite.	Corneal vascularization; cloudy lens; hemorrhagic eyes; cataracts photophobia; dim vision; incoordination; abnormal pigmentation of iris; scleral congestion; cheilosis and angular stomatitis; impaired erythrocyte formation.
Pyridoxine	Nervous disorders; epileptiform fits; hyperirritability; ataxia; anemia; loss of appetite; edema of peritoneal cavity; colorless serous fluid; blue-green coloration on back; post-mortem rigor mortis occurs rapidly; rapid and gasping breathing; flexing of opercles.	Nervous disorders; epileptiform fits; hyperirritability; ataxia; anemia; loss of appetite; edema; symmetrical dermatosis; dermal lesions; iron deposition in liver; rise in serum iron.
Pantothenic acid	Clubbed gills; prostration; loss of appetite; necrosis and scarring; cellular atrophy; gills covered with exudate; sluggishness; general "mumpy" appearance.	Prostration; loss of appetite; necrosis and scarring; cellular atrophy; spectacle alopecia; generalized scaling and dermatitis; diarrhea; hyperemia of intestine; myelin degeneration of nerves.
Inositol	Poor growth; distended stomach; increased gastric emptying time.	Poor growth; increased gastric emptying time; alopecia; nutritional encephalomalacia.
Biotin	Loss of appetite; lesions in colon; coloration; muscle atrophy; spastic convulsions; fragmentation of erythrocytes.	Loss of appetite; poor growth; muscle atrophy; seborrheic skin disease; generalized erythema; spastic gait; necrosis of fibers; increased sarcolemma.
Folic acid	Poor growth; anemia; lethargy; fragility of caudal fin; dark coloration.	Poor growth; lethargy interspersed with convulsions; megaloblastic erythropoesis; nutritional cytomenia; infarction of spleen.
Choline	Poor growth; poor food conversion; hemorrhagic kidney and intestine.	Poor growth; poor food conversion; aversion to food; fatty infiltration of liver; necrosis and scarring; reddish kidney; hemorrhagic eyes.
Nicotinic acid	Loss of appetite; lesions in colon; jerky or difficult motion; weakness; edema of stomach and colon; muscle spasms while apparently resting.	Loss of appetite; lesions in colon; jerky or spastic gait; weakness; pain; skin eruptions; edema of stomach and colon; anorexia; diarrhea; neurological lesions; fatty livers; vessel dilation.
Vitamin B_{12}	Poor appetite; erratic hemoglobin and erythrocyte counts; fragmentation.	Pernicious anemia; macrocytic anemia; sprue; low or poor growth in young.
p-Aminobenzoic acid	No abnormal indication in growth, appetite, mortality.	Alopecia in rat and poor growth in chick.
Ascorbic acid	No abnormal indication in growth, appetite, mortality.	Scurvy; capillary fragility; immature fibroblastic formation.

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[1] West and Todd ('51).
[2] Wooster ('54).

Under the experimental conditions used, inconclusive results were obtained with the vitamin B_{12}-deficient group of fish. No abnormal indications in appetite, growth, mortality or post-mortem examinations of external and internal organs were observed in the ascorbic acid- or para-aminobenzoic acid-deficient lots of salmon. The average weight of these fish

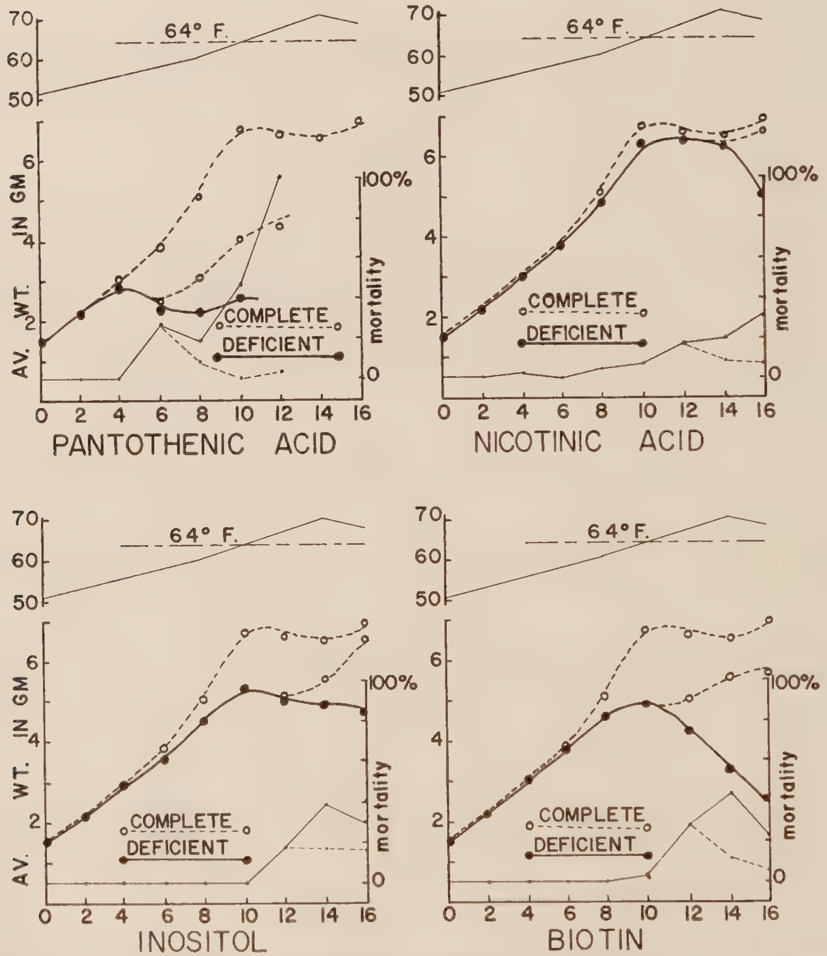

Fig. 2 Growth and mortality of chinook salmon fed complete diets and diets deficient in pantothenic acid, nicotinic acid, inositol or biotin. For identification of various curves, see legend for figure 1.

paralleled closely those of the complete test lots and a simple Student t_N test did not differentiate between any specific point on the curves comparing growth of the control lots with vitamin B_{12}-, ascorbic acid-, or para-aminobenzoic acid-deficient groups of salmon.

Individual samples from each of the deficient groups of fish were removed for histological analysis immediately following the bi-weekly weighing period. Total blood cell counts and hemoglobin determinations of these samples seemed normal in all lots of fish with the exception of folic acid- and vitamin B_{12}-deficient groups. A large number of undeveloped nuclei and low total blood cell counts (1,000,000 to 1,100,000) were observed in the folic acid-deficient lot and the hemoglobin determinations averaged 9.0 gm/100 ml blood. In the vitamin B_{12}-deficient group, erratic hemoglobin values were found varying from 9.0 to 13.5 gm/100 ml blood and the total blood cell counts varied from 900,000 to 1,500,000. In the larger fish of this group the erythrocytes appeared wrinkled or fragmented and many undeveloped cells were present.

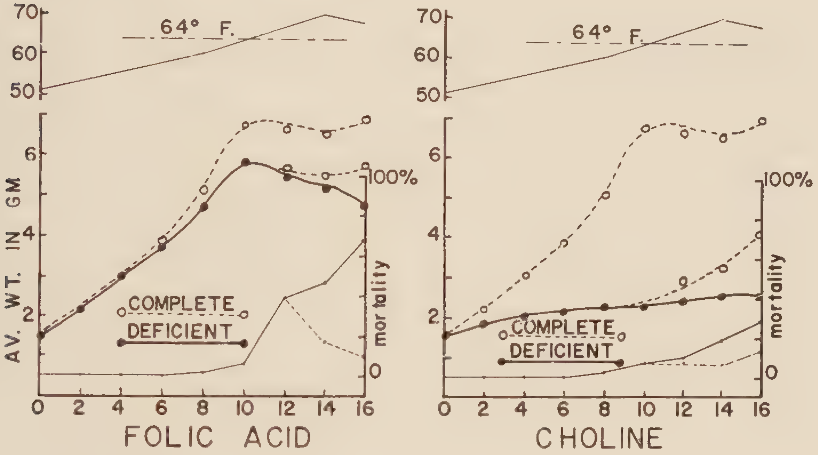

Fig. 3 Growth and mortality of chinook salmon fed complete diets and diets deficient in folic acid or choline. For identification of various curves, see legend for figure 1.

Unfortunately a hematologist was not available for complete study of these blood cells.

When the missing vitamin was returned to the deficient groups of fish, recovery was rapid in most cases, with the disappearance of observable deficiency syndromes. In the case of riboflavin-deficient fish where the eye damage had resulted in complete blindness, these individual fish failed to eat and soon died. When only one eye was badly affected the fish did recover normal body functions, but the damaged eye did not repair and had no detectable vision at the end of the experimental period. Pantothenic acid-deficient fish varied from a mild swelling of the gill filaments to a severe flaring of the opercles. These latter fish seemed to have difficulty in eating and only about 50% recovered with no observable deficiency syndrome by the end of the experiment. In all other lots of deficient fish, replacement of the missing vitamin caused the disappearance of any observable deficiency syndrome by the end of the experimental feeding period.

Results of the histological analysis of the normal, deficient and recovery groups of fish on each of these vitamin deficient diets will be published at a later date. At that time interpretation of the reversibility of the deficiency syndromes will be discussed.

Experiment 3. Using a water supply with a constant temperature (58°F.) and paired troughs of 300 fish each, confirmatory specific deficiency syndromes were observed with diets deficient in thiamine, riboflavin, pyridoxine, biotin, pantothenic acid, folic acid, inositol, nicotinic acid, or choline. Vitamin B_{12}-deficient fish again failed to show conclusive symptoms.

SUMMARY

A vitamin-test diet consisting of a vitamin-free basal ration supplemented with crystalline vitamins was formulated which would maintain chinook salmon fingerlings for a period sufficient for the development of water-soluble vitamin deficiency syndromes.

Deleting the water-soluble vitamins one at a time from the complete test diet caused typical specific deficiency syndromes in chinook salmon which were comparable to those observed in other experimental animals.

Requirements for thiamine, riboflavin, pyridoxine, pantothenic acid, niacin, inositol, biotin, folic acid and choline were demonstrated.

Inconclusive results were obtained for vitamin B_{12}-deficient fish.

Under the experimental conditions used, no deficiency syndromes were observed in ascorbic acid- or para-aminobenzoic acid-deficient lots of salmon.

ACKNOWLEDGMENTS

Appreciation is expressed to John A. Coates, State of Washington Department of Fisheries for his diligent help in diet preparation and hatchery operations; to Dr. Hans Neurath and to Dr. Earl R. Norris, University of Washington, Department of Biochemistry, for their stimulating interest and constructive criticisms; to Dr. Richard Van Cleve, University of Washington School of Fisheries, for furnishing the hatchery space for the initial experiment; to Dr. R. T. Major of Merck & Company for furnishing the crystalline vitamins; to Dr. Robert R. Rucker, U. S. Department of Interior, Fish and Wildlife Service, for investigating the fish pathology.

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NUTRITION OF SALMONOID FISHES

IV. AN AMINO ACID TEST DIET FOR CHINOOK SALMON[1]

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INTRODUCTION

A prerequisite for determining the amino acid requirements of salmon should be the development of a satisfactory test diet which will maintain chinook salmon *(Oncorhynchus tshawytscha)* for a period sufficient for the development of any amino acid deficiency syndrome. In order to allow the investigator the greatest experimental control in adjusting the levels of individual amino acids in the protein component of the diet, a mixture of crystalline amino acids was desirable for the nitrogen source. Adequate levels of vitamins, carbohydrates, fats and minerals for at least a 20-week feeding period with chinook salmon fingerlings were established previously (Halver, '57). Wood, Griffin and Snieszko ('54) tested various synthetic inert binders for fish diets and found that carboxymethylcellulose (CMC) was suitable for used in studies with purified diets. Combining the above ingredients and furnishing the nitrogen source with natural L-isomers of the amino acids common to plant and animal proteins, an amino acid test diet was formulated and tested against the complete vitamin-test diet previously mentioned (Halver, '57).

EXPERIMENTAL

As a first approximation of the levels of individual amino acids to be fed as the nitrogen source, keeping the other major

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[1] Presented at the meetings of the American Institute of Nutrition, Atlantic City, New Jersey, April, 1956.

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components of the ration as close as possible to those used previously in the vitamin-test diet, assays were completed on the amino acid composition of yolk-sac fry and initial-feeding fingerlings. These values differed from the calculated levels of amino acids in the casein-gelatin protein component of the control diet; it seemed appropriate, therefore, to test

TABLE 1

Amino acid composition of yolk-sac fry and salmon fingerlings and of experimental diets

INGREDIENT	MICROBIOLOGICAL ASSAYS			DIET MIXTURES	
	Yolk-sac fry	Salmon fingerlings	Control	C-G	YSF
	gm	*gm*	*gm*	*gm*	*gm*
L-Arginine(· HCl)	1.41	1.36	4.44	5.00	2.50
L-Histidine(· HCl · H_2O)	2.07	1.80	2.13	2.50	3.00
L-Isoleucine	4.76	5.38	4.11	4.00	6.00
L-Lysine(· HCl)	2.09	2.07	5.05	5.00	3.00
L-Methionine	1.23	1.30	1.91	2.00	2.00
L-Phenylalanine	2.69	2.64	3.84	4.00	3.00
L-Threonine	1.00	0.95	2.47	2.50	1.50
L-Tryptophan	0.97	1.00	0.74	1.00	1.50
L-Tyrosine	2.32	2.05	3.86	4.00	2.50
L-Valine	1.10	0.91	4.29	4.00	1.50
Glycine			4.70	5.00	5.00
L-Alanine			3.40	3.50	5.00
L-Aspartic acid			4.20	5.00	5.00
L-Cystine			0.20	0.50	2.50
L-Glutamic acid			13.60	8.00	10.00
L-Proline			6.08	5.00	5.00
L-Serine			3.17	3.00	5.00
Total	19.64	19.46	68.19	70.00	70.00
Amino acid mix				70	70
Vitamin-free casein			55	. .	. .
Gelatin			15	. .	. .
Corn oil			5	5	5
Cod liver oil			2	2	2
Dextrin, white			6	6	6
Mineral mix			4	4	4
Vitamin mix			3	3	3
alpha-Cellulose flour			8	. .	. .
Carboxymethylcellulose			2	10	10
Water			300	100	100

two amino acid mixtures one approximating the amino acid content of yolk-sac fry and salmon fingerlings and the other that of casein-gelatin. Each mixture was fed at the level in the control diet (table 1). The amounts of the amino acids, glycine through serine (table 1), added to the amino acid mixture exceeded the content of these respective amino acids found in the casein-gelatin control with the exception of glutamic acid and proline. These two were lowered in amounts to adjust the final amino acid mixture to 70% of the diet.

Prior to preparing the mixtures, each lot of individual amino acids was checked for purity by comparing the specific rotation values with those listed in the literature. All lots checked within 90% of recorded values with the exception of L-threonine which was of course (—) instead of (+) as listed in the handbook.

A preliminary test indicated at least 5% carboxymethylcellulose would be necessary to obtain satisfactory feeding consistency with the diet ingredients proposed and to obtain this amount it was necessary to modify the levels of some less essential components in the complete vitamin test diet (Halver, '57). An introductory 10-week feeding trial comparing the original complete vitamin-test diet with the modifications necessary to increase the inert ingredients to 11.7% of the dry weight of the diet substantiated the changes at least during this growing period (see table 2). Therefore, the corn oil and the carbohydrate components were reduced 2% each and replaced with alpha-cellulose flour. In the event that carboxymethylcellulose would inhibit growth in salmon, 2% CMC was included in the modified control diet. The mineral mixture and vitamin supplement were prepared as described previously in the vitamin studies (Halver, '57).

The amino acid test diet was prepared in a dough mixer equipped with a wire beater. To prepare 200 gm of diet, 70 gm amino acid mixture, 5 gm corn oil, 2 gm cod liver oil, 6 gm white dextrin, 4 gm mineral mixture and 3 gm alpha-cellulose flour containing the vitamin supplement were blended in the dry state until a homogeneous mixture was obtained. To these ingredients was added 100 ml of distilled water that had been heated to 80 to 90°C. The mass was then stirred until homogeneous and until the soluble components were in solution. With the mixer in motion, 10 gm carboxymethylcellulose was added slowly and as the diet began to solidify, the speed of the blender was increased to incorporate air into the mixture. The final diet (200 gm) was about the consistency of bread dough. When stored in low form fruit jars in the refrigerator, the firmness increased and the diet could be fed easily through a garlic press without wastage. Only as much diet as needed for one week of feeding was prepared and stored at 4 to 6°C. until used.

For comparison during the feeding trials, the modified vitamin test diet was prepared by methods previously described and stored under refrigeration until used (Halver, '57).

A random sample of yolk-sac chinook salmon fry was obtained from the U. S. Fish and Wildlife Service Spring Creek Salmon Hatchery and acclimated to the experimental constant temperature (46°F.) spring water supply. After the yolk-sacs had been absorbed, the fry were taught to feed on the control diet. When all fish were feeding actively on the control diet, 6 representative random samples of 200 fish each were hand counted into 4-foot screened plastic-coated hatchery troughs supplied with apparently pathogen-free water at three gallons per minute. The fish were weighed to confirm representative weights (100 ± 2 gm), and after one day of rest and acclimation, were started on the feeding regime.

Fish were fed three times daily, 6 days weekly with no diet fed on Sundays. Bi-weekly weights were taken by one individual (GDG) throughout the feeding period by removing the entire population in a net, draining the water over a 10-second period, pouring into a tared container on a solution balance, weighing to within one gram and immediately returning to the trough. Dead fish were removed as soon as observed and the troughs were cleaned daily to prevent both the accumulation of feces and the growth of slime and fungus. Only as much food as the fish would consume within one minute after presentation was expelled through a garlic press into the upper one-third of the trough by one individual throughout the feeding period. Equipment common to all lots was rinsed in disinfectant after each use to prevent transfer of nutrients or disease organisms from one lot to the next trough. At the 6-, 10- and 14-week weighing periods, 5 fish samples were removed, examined for possible external or internal abnormalities, and were preserved for future histological analysis.

After the 10th week of feeding, the growth curves of the two lots of fish fed the amino acid mixture corresponding to the approximate amino acid content of yolk-sac fry protein were divergent from the other groups and were discontinued in the interest of economy.

The remaining 4 troughs were continued until the 14-week feeding period was terminated. At this time, prior plans necessitated use of the spring water system to initiate the qualitative experiments to be reported in a later paper,[2] and the 4 troughs of fish were transferred to the river water system (46 ± 2°F.). Unfortunately, the river system was contaminated with *Hexamitus salmonis* [3] and during the 15th week of feeding, all 4 groups exhibited a severe octomitis disease infection. At the termination of the 16-week feeding period (two weeks in river water), all fish examined showed *Hexamitus* in the gastro-intestinal tract, the fish exhibited little appetite and greater mortality was observed in the final two weeks of feeding than in the preceding 14 weeks in the spring water environment.

RESULTS AND DISCUSSION

After 14-weeks of feeding the amino acid test diet corresponding to the approximate amino acid content of the casein-gelatin control diet, no abnormal indications in appetite, growth, mortality, or post-mortem examinations of external and internal organs were observed. The growth of these fish compared favorably with those fed the modified vitamin test control diet as can be seen by examining figure 1. Mortality was normal (4%) for the 14-week feeding period, comparing favorably with that found previously in semi-purified salmon diet studies (Halver, '57). The fish in lots YSF, although growing more slowly, did not show any other gross symptom or abnormality. At the end of this experiment (10 weeks), no pathological condition was revealed upon cursory examinations. Similar examinations indicated normal healthy fish in the lots fed either the amino acid test diet or the control diet (14 weeks).

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[2] To be published later.

[3] Synonym — *Octomitis salmonis* commonly used by fish cultural personnel.

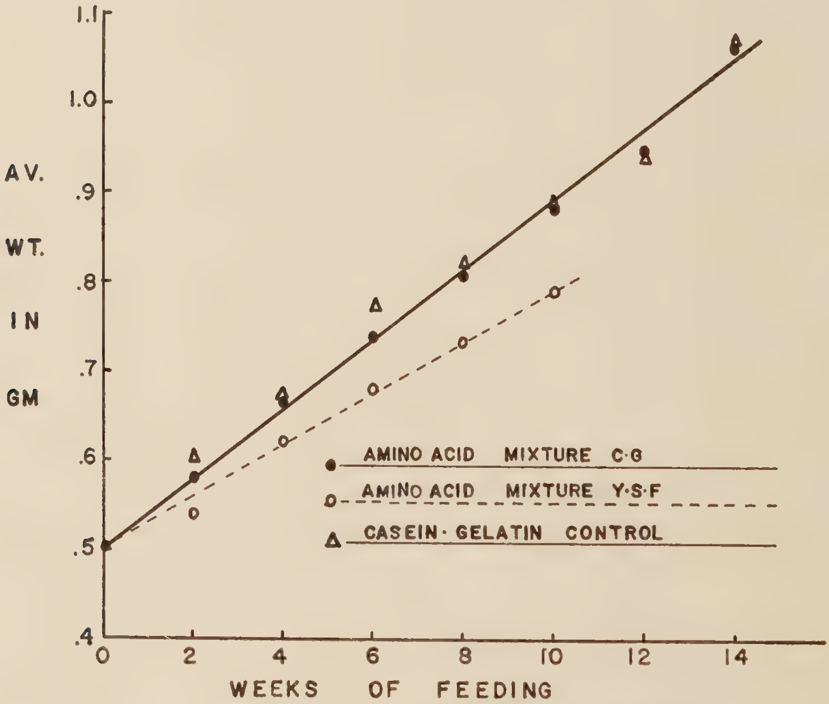

Fig. 1 Growth of salmon fingerlings on amino acid test diets.

Apparently it was not necessary to increase the caloric intake above that found in the control diets for proper utilization of the free amino acids used in these mixtures (Rose, Coon and Lambert, '54; Fisher and Johnson, '56), and since the caloric intake was nearly identical for the two amino acid test diets, the discrepancy in growth with the YSF mixture must have been due to improper amino acid balance. The magnesium content of the control diet seemed adequate for utilization of free amino acids (Benton et al., '55; Heincke, Harper and Elvehjem, '55), and it was not necessary to increase the intake in order to obtain growth with the C-G amino acid mixture comparable to that of the control lots.

Feed efficiency and utilization was difficult to measure because the diet sank slowly in the trough and undoubtedly certain soluble portions leached into the water. Attempts to minimize this effect and to feed slowly enough to insure that all the diet would be consumed before it reached the bottom of the trough were undertaken but even when the greatest care was used, a small portion of the ration would be left on the bottom before the majority of the actively-feeding salmon would indicate any food refusal. Undoubtedly, a more efficient binder for the dry ingredients would still allow them to become available for digestion and assimilation, would improve the efficiency of the diet, and would furnish a more accurate measurement of food conversion and protein efficiency ratio (table 2).

Deleting the crystalline amino acids individually from the amino acid test diet C-G offers the possibility of developing specific amino acid deficiency syndromes and determining the amino acids that are indispensable for chinook salmon. This diet should furnish a lucrative tool for protein requirement studies and contribute to the determination of the quantitative amino acid requirements of salmon. The experimenter would not be shackled with the use of protein mixtures to change the dietary intake of one or more amino acids, but would have positive experimental control over each amino acid in the protein component of the diet.

TABLE 2

Growth, mortality and food conversion of chinook salmon on various amino acid test diets and on control diets

RATION	NUMBER OF FISH	INITIAL WEIGHT	FINAL WEIGHT	WEEKS OF FEEDING	PER CENT GAIN	PER CENT MORTALITY	DRY FOOD FED	CONVERSION RATIO
		gm	*gm*				*gm*	
CVTD[1]	500	0.50	0.91	10	92	2.0	365	1.8
	500	0.50	0.92	10	94	2.5	365	1.8
Control	500	0.50	0.90	10	90	2.4	360	1.8
	500	0.50	0.93	10	96	1.8	360	1.8
Control	200	0.50	1.07	14	114	4.5	200	1.9
	200	0.50	1.09	14	118	4.0	200	1.8
YSF[2]	200	0.50	0.80	10	60	5.5	160	2.8
	200	0.50	0.78	10	56	2.5	160	3.0
C-G[3]	200	0.50	1.06	14	112	4.5	265	2.5
	200	0.50	1.06	14	112	3.5	265	2.5

[1] Complete vitamin test diet (Halver, '57).

[2] Yolk-sac fry — salmon fingerling amino acid mixture test diet.

[3] Casein-gelatin amino acid mixture test diet.

SUMMARY

An amino acid test diet was formulated which would maintain chinook salmon fingerlings for at least a 14-week growing period under the experimental conditions used.

The amino acid mixture comprising the nitrogen source consisted of crystalline L-amino acids bound together with the other diet components by carboxymethylcellulose.

An amino acid mixture approximating the content of amino acids in yolk-sac fry and fingerling salmon protein failed to yield acceptable growth when compared with the above amino acid mixture or the control diet.

The use of an amino acid test diet for salmon in which the experimenter has control over each amino acid in the protein component, should simplify the determinations of the qualitative and quantitative amino acid requirements of chinook salmon.

ACKNOWLEDGMENTS

The author wishes to thank Dr. Edwin T. Mertz, Department of Biochemistry, Purdue University, for his suggestions and constructive criticism of the protein levels to be fed; Mr. Donald C. DeLong of the same department for completing the microbiological amino acid assays of yolk-sac fry and salmon fingerlings and Mr. G. Duane Gahimer of the Salmon Nutrition Laboratory, U. S. Fish and Wildlife Service, for conducting the routine hatchery feeding and weighing procedures.

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THE RATE OF FEEDING OF THE COMMON OYSTER DRILL, UROSALPINX CINEREA (SAY), AT CONTROLLED WATER TEMPERATURES

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THE RATE OF FEEDING OF THE COMMON OYSTER DRILL, UROSALPINX CINEREA (SAY), AT CONTROLLED WATER TEMPERATURES

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Information on the voracity of the oyster drill, *Urosalpinx cinerea* (Say), within certain ranges of water temperature has been reported by a number of investigators, but evaluation of their destructiveness at specific temperatures maintained within close limits is virtually non-existent. In addition, the conclusions regarding the destructiveness of drills within the different temperature ranges are drawn from observations made at widely separated geographical areas (Carriker, 1955).

Observations by Stauber (1950) and Loosanoff and Davis (1950–51) on certain activities of drills from different areas of the North Atlantic Coast suggest the existence of distinct physiological races. If such races exist, a temperature-dependent activity, such as feeding, determined for drills from one area would not necessarily be applicable to drills of another habitat. Therefore, we have attempted to establish the feeding rate of a single geographical population of oyster drills at several constant temperatures. It was felt that such a study would not only provide more detailed information about the predation of drills, but also present a basis of comparison for investigators interested in the problem of physiological races.

METHODS

A bank of wooden frames, constructed to hold a number of enamel trays (18″ × 20″ × 3″), was arranged on a laboratory water table. Each tray was supplied with a separate, continuous flow of sea water. Temperatures were adjusted by mixing cold and heated sea water in glass cylinders, just above the frames, giving each bank of trays a separate supply of water at a constant temperature (Loosanoff, 1949). Water in the trays was maintained at approximately ± 1.0° C. of the temperature desired.

Since the drills had a tendency to move up the sides of the tray and leave the water, covers were made to fit into each tray to keep the drills below the water line. They were constructed of Lucite plastic frames with a covering of ⅛″-mesh Saran plastic screening.

The salinity of the water deviated only slightly from 25‰ throughout the experiments and is, therefore, considered to have exerted no influence on differential feeding at the various temperatures.

To obtain a more comprehensive evaluation of feeding by drills at different temperatures, two species of bivalves, the common oyster, *Crassostrea virginica* Gmelin, and the mussel, *Mytilus edulis* Linné, were used as foods in separate experiments.

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Each tray contained 20 adult, Long Island Sound drills measuring from 20.0 to 25.0 mm. in height, and either 30 to 40 oyster spat, ranging in size from 10.0 to 30.0 mm., or 40 mussels, ranging in size from 20.0 to 30.0 mm. Spat were growing on cultch (old oyster shells) in such numbers that four to five shells supplied the total needed. The oyster spat clusters or mussels were so distributed about the tray that no large concentration of food occurred at any one point. The drills were dispersed throughout the tray to decrease the opportunity for feeding by two or more drills on the same bivalve. At no time during the experiments did the drills consume all of the bivalves available in any tray, thereby indicating that feeding was maximal for each feeding period.

The drills were brought to the experimental temperatures by keeping them for two to three hours at each five-degree level until the desired temperature was reached. After the experiment was begun the number of bored bivalves, as well as the number and condition of drills present, was ascertained at regular intervals. Following each such examination, oyster spat or mussels were added to replace those destroyed by the drills. Mortality of drills was low at all temperatures, except 30.0° C. All dead drills were replaced by drills from stocks kept at the same water temperature as the experimental groups to assure that their prior conditioning was the same.

RESULTS

The feeding rates are expressed as the number of bivalves destroyed per drill during one week of feeding. Since low temperatures could not be maintained during the spring and summer, observations on the groups at 5.0° C. were discontinued after 52 days, on the 10.0° C. groups, at 69 days, and on the 15.0° C. groups, at 90 days; while the groups at 20.0°, 25.0° and 30.0° C. were under observation for 102 days (Table I).

At 5.0° C. the drills did not feed, nor did they show any tendency to attack the spat during the 52 days of the experiment. They usually remained in groups, each

TABLE I

Feeding rate of U. cinerea on oyster spat, size range 10–30 mm., at controlled water temperatures

Temperature ° C......	5.0		10.0		15.0		20.0		25.0		30.0	
Tray................	1	2	1	2	1	2	1	2	1	2	1	2
No. of drills	20	20	20	20	20	20	20	20	20	20	20	20
Feeding period (days)	52	52	69	69	90	90	102	102	102	102	102	102
No. of spat consumed	0	0	49	41	124	133	313	355	429	398	285	327
Spat consumed per drill per week	0	0	0.25	0.21	0.48	0.52	1.07	1.21	1.47	1.37	0.98	1.12

drill with the foot extended and attached firmly to the tray. Movement of a few inches by some drills, as shown by mucus paths, was noted on several occasions.

Feeding at 10.0° C. appeared to be limited to occasional attacks by individual drills since the rate of feeding was only about one spat per drill every four to five weeks. The rate of feeding on oyster spat increased as the temperature increased from 10.0° to 25.0° C. The rate approximately doubled for each five-degree increase in water temperature from 10.0° to 20.0° C. However, the next five-degree rise, to 25.0° C., increased the rate of feeding only about 25 per cent over that at 20.0° C., and a distinct decrease in the rate of feeding occurred at 30.0° C. Thus, the optimum temperature for feeding of drills on oyster spat was at or near 25.0° C.

The drills maintained at 30.0° C. were also slower in turning over and attaching to the tray than those kept at 25.0° C. On two occasions, when the temperature rose to about 34.0° C., 70 to 80 per cent of the drills were killed, although in neither instance were they exposed to this temperature for more than 16 hours. The surviving drills were not attached to the tray or to the oyster spat, as they usually were at 30.0° C. These observations suggest that while drills do feed at 30.0° C., this approaches the lethal temperature level.

Table II

Feeding rate of U. cinerea on mussels, size range 20–30 mm., at controlled water temperatures

Temperature ° C.	10.0		15.0		20.0		25.0		30.0	
Tray	1	2	1	2	1	2	1	2	1	2
No. of drills	20	20	20	20	20	20	20	20	20	20
Feeding period (days)	34	34	57	57	57	57	44	44	44	44
No. of mussels consumed	1	4	39	32	88	73	101	109	89	105
Mussels consumed per drill per week	0.01	0.04	0.24	0.20	0.54	0.45	0.80	0.87	0.71	0.82

Comparable data for oyster drills feeding on mussels show that the optimum feeding temperature again lies near 25.0° C. (Table II). Apparently, only a few of all the drills kept at 10.0° C. fed during the 34 days of the experiment. The rate of feeding at 15.0° C. approximated one mussel per drill every five weeks. This rate was about doubled for each five-degree rise in temperature from 15.0° to 25.0° C. Although the rate of feeding at 30.0° C. was lower than that at 25.0° C., it was not as low as would be expected from the results when oyster spat were used as food. Probably, the rate of drill feeding at 30.0° C., in the mussel-fed experiment, was somewhat higher due to differences in handling. It was necessary to examine each tray and change the mussels daily to avoid a high mortality and resultant bacterial decomposition of mussels at 30.0° C. Thus, the drills may have been induced to attack more mussels because they were unable to feed without interruption.

Statistical treatment of the data by analysis of variance indicates that differences in feeding rate between temperature levels are highly significant (F = 85.96 with df = 4,5 for mussels as food and F = 143.84 with df = 5,6 for oyster spat as food; both values being significant beyond the 0.001 level). In order to determine which of the differences between temperatures were significant, a test for significance of gaps between means was applied (Bliss and Calhoun, 1954). Results of this test indicated a minimum difference between means of 0.162 for oyster spat as food. Thus, all gaps between means are significant except between 20.0° and 30.0° C. (Fig. 1). With mussels as the food organism, the minimum difference was 0.136. Thus, all gaps between means are significant except between 25.0° and 30.0° C.

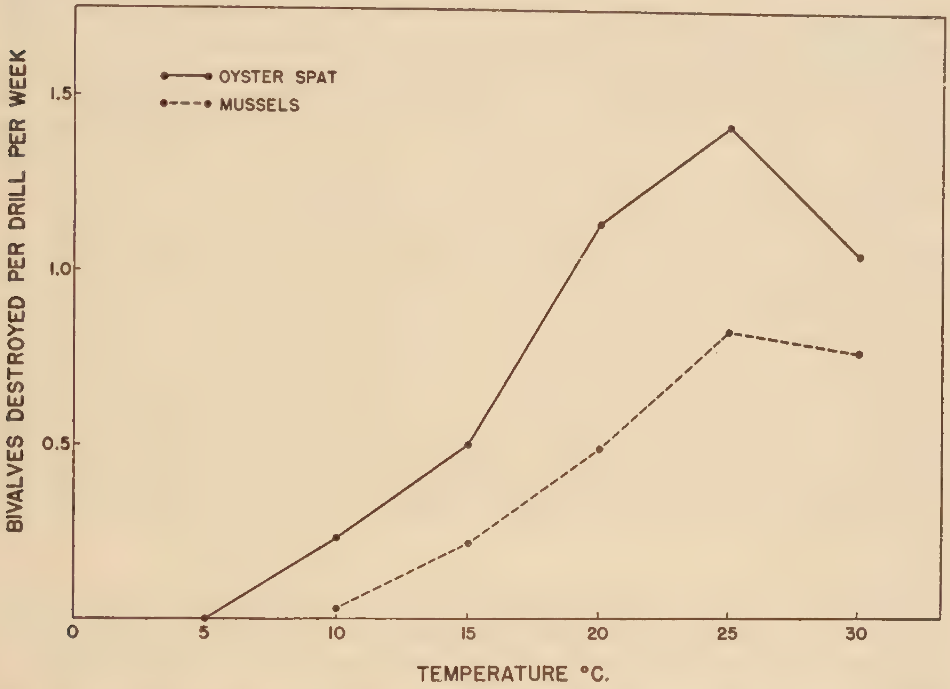

FIGURE 1. Feeding rates of *U. cinerea* at constant temperatures on young oysters or mussels. (Points are based on combined data of replicates at each temperature level.)

DISCUSSION

The rate at which the drills destroyed oyster spat was higher than the rate at which they destroyed mussels at each of the temperatures used in these experiments (Fig. 1). This may indicate a preference of the drills for oyster spat, rather than mussels, as food. However, it is more probable that much of this difference was due to the spatial arrangement of the mussels in the tray, which necessitated more movement by the drills between feedings than when oyster spat, growing in clusters, was used for food. In addition the slightly larger average size of the mussels gave the drills somewhat more food per mussel killed than per oyster spat.

This comparison of feeding by drills on two species of bivalves shows a marked increase in destruction for each five-degree rise in water temperature within the range from 10.0° to 25.0° C. With either food, the peak of feeding occurred at 25.0° C. Since this temperature is seldom reached over the oyster beds in Long Island Sound, it is doubtful that drills in our waters are often feeding at their maximum rate.

As the drills did not feed at 5.0° C. and their rate of feeding on oyster spat was lowest at 10.0° C., a similar experiment was run at 7.5° C. to determine whether this temperature was above or below the threshold at which feeding on spat could occur. As with drills at 10.0° C., feeding at 7.5° C. was sporadic. In one experiment when 20 drills were used, one spat was killed after 27 days and two more during the next 37 days. Another group of 20 drills destroyed two to three spat per week during the first two weeks, did not feed for the next two weeks and, again, killed two to three spat per week for the final four weeks of the experiment.

The minimum temperature for feeding of drills has been reported as 9.5° C. (Galtsoff *et al.,* 1937), 9.0° C. (Loosanoff and Davis, 1950–51), 8.0° C. (Engle, 1953), and 6.5° C. by Andrews and McHugh (Carriker, 1955). The last figure was an average over a period in which the maximum temperature reached 9.5° C. and, therefore, cannot be regarded as the actual temperature at which feeding occurred. The lower temperature limit for feeding of 7.5° C. established in this study is in general agreement with these figures. However, it is apparent that short-term observations will not suffice to determine the lower temperature limit for feeding. Drills went as long as 27 days at 7.5° C. before any feeding occurred, and thus, it is possible that drills will feed at even lower temperatures, if kept for many months. In this study no feeding on oyster spat was observed at 5.0° C. during 52 days of exposure.

The author wishes to express thanks to Dr. V. L. Loosanoff for his many helpful suggestions and guidance throughout the experimental work, to Mr. C. A. Nomejko for preparation of the graph, and to Mrs. Barbara Myers for statistical treatment of the data.

SUMMARY

1. Feeding by drills, *Urosalpinx cinerea* (Say), of Long Island Sound did not occur at 5.0° C.

2. The lower temperature limit for feeding was about 7.5° C., although feeding at this temperature was intermittent.

3. The feeding rate increased steadily as the water temperature was raised from 10.0° to 25.0° C., and decreased as the temperature was increased from 25.0° to 30.0° C.

4. The optimum temperature for feeding, when either *Crassostrea virginica* (Gmelin) or *Mytilus edulis* Linné was used as food, was 25.0° C.

5. The upper temperature limit for feeding was about 30.0° C.

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Notes on the Biology of the Wahoo in the Line Islands

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Notes on the Biology of the Wahoo in the Line Islands

Edwin S. Iversen[1] and Howard O. Yoshida[2]

Incidental catches of wahoo, *Acanthocybium solandri* (Cuvier and Valenciennes), have been made by the Pacific Oceanic Fishery Investigations, a branch of the U. S. Fish and Wildlife Service, during experimental tuna fishing conducted from 1950 to 1956. The exploratory fishing, which extended from 180° to 130°W. longitude and from 10°N. to 13°S. latitude, has been carried out both close to the islands and in the open sea. The bulk of our wahoo data came from the Line Islands, which from south to north are: Starbuck, Malden, Jarvis, Christmas, Fanning, Washington, and Palmyra islands, and Kingman Reef. They extend in a general northwesterly direction from 5°S. latitude and 155°W. longitude to 7°N. latitude and 163°W. longitude. Although there is no organized fishery in the islands, the copra plantation workers (Gilbertese and Ellice islanders) use beach seines to capture a variety of lagoon and reef fishes and hand lines to catch an occasional tuna or wahoo.

Most of the published reports dealing with the wahoo are brief and are concerned primarily with its occurrence and distribution. The presence of wahoo was first noted in the Line Islands by Fowler (1938: 277). Rosa (1950: 75–77) lists a number of references which are of interest principally to taxonomists. In general the biology of the species is poorly known and has not been previously considered in the central Pacific.

The wahoo, a member of the order Scombriformes, is a slender, streamlined fish wit a sharp pointed head (Fig. 1). The mouth i large and is armed with razor-sharp teet Wahoo may weigh over 130 pounds an reach a length of nearly 7 feet. The body i steel-blue above and pale blue below. A serie of bluish-black vertical bars, which fade soo after death, are present on the sides of th body. These fish are said to be very rapi swimmers and to make spectacular leaps ou of the water.

The species is cosmopolitan in tropical an subtropical areas, and ranges at least as fa north as Hawaii, where it is called "ono. Jenkins (1904: 441) examined wahoo in th Honolulu Market and reported that, "This i the first record of the species in Honolulu. In Hawaii today the species is of some sligh importance as a sport fish. It is also sol commercially on the fresh fish market i Honolulu, but is of secondary importanc In 1953 the catch of 50,813 pounds durin the year was sold for $11,166.94.

METHODS

The majority of fish available for this stud were taken on standard surface trolling gea which is described by Bates (1950). Th method of trolling employs about six line attached to two long poles extending ou board, one from either side of the vesse Trolling was mainly carried out from approx mately 200 yards to 3 miles from the fringin reefs of the various islands. Some catches wer also made on longline (flagline) gear, described by Niska (1954). Longline gear, whic fishes well below the surface, was generall

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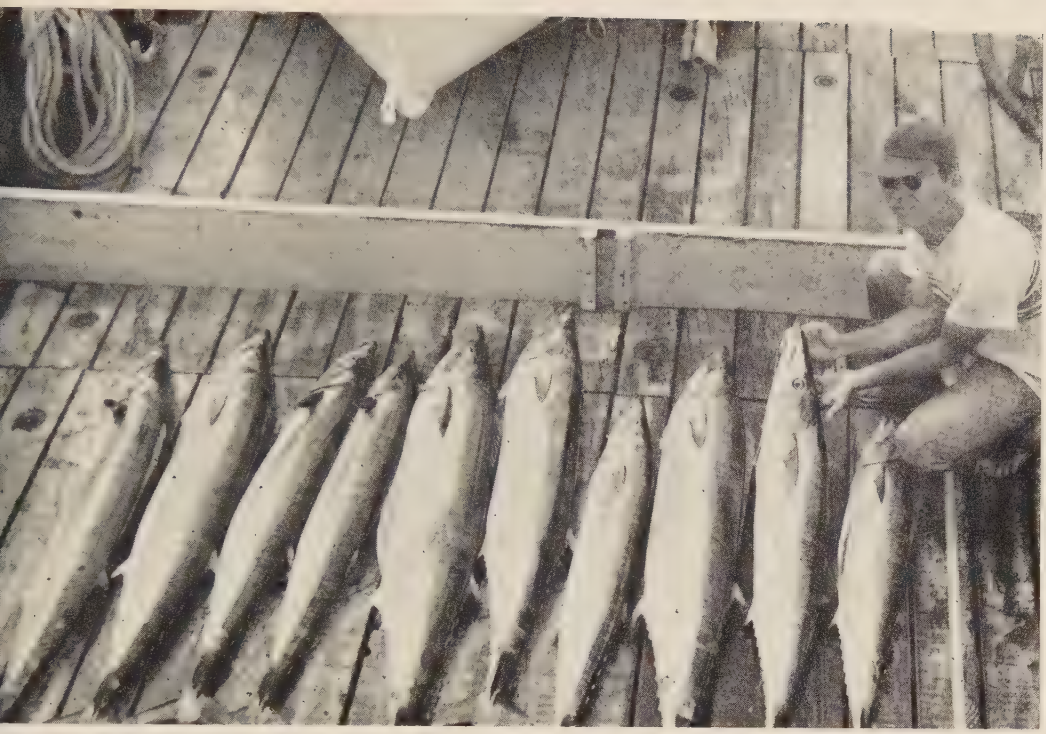

FIG. 1. Wahoo captured by surface trolling in the Line Islands.

ised in the open ocean, but some longline tations were occupied as close as 5 to 10 niles from land.

Length measurements were made in millineters, using calipers. The fixed arm was laced on the tip of the upper jaw with the nouth closed, and the sliding arm of the aliper was placed at the fork of the caudal in, being careful to depress the fleshy flap Marr and Schaefer 1949: 242). Weights were aken in pounds, using a steelyard rigged to davit on the deck of the vessel. Some diffiulty was encountered in accurately weighing he fish when the vessel was under way, but nost weights were taken when the vessel was n smooth waters or at anchor.

In preparing length-frequency distributions he lengths were first combined in 4-cm. roups and then smoothed by a moving averge of three. Modal groups in these distribuons are defined as the size classes with the ighest frequencies in the smoothed distributions. Where several adjacent size classes are similar in height after smoothing, the center of these size classes is designated as the mode.

Stomach contents of the fish were recorded in the field as soon as possible after the fish were captured. The few parasites returned to the laboratory for examinations were preserved in 10 per cent formalin.

Measurements of ova for spawning and fecundity analysis were made with a dissecting microscope, employing a micrometer eyepiece measuring in units of 0.023 mm. The eggs were not perfectly symmetrical, so to avoid selection the "diameter" measured was the distance between two lines of the micrometer tangent to the eggs, the micrometer being held in one position during a series of measurements, following the method of Clark (1934: 7).

AVAILABILITY

Wahoo do not appear to form large compact schools. This simplifies the problem of estimating their availability. Kishinouye (1923: 412) states that wahoo do not "make a school." Taylor (1951: 278), in discussing wahoo off North Carolina, reports that they do not form schools but that males and females group in pairs at spawning time. From our trolling catches close to shore it seems that this species tends to form small, loose, feeding aggregations, since we found that occasionally several wahoo would hit the lures simultaneously. Chapman (1946: 166) believes that they may form schools, for some of the wahoo he caught near Palmyra Island had frayed caudal fins, which he attributed to crowding in schools.

Some general knowledge of the vertical and horizontal distribution of wahoo is important when estimating the availability of this species. These aspects of the distribution can be roughly inferred from a comparison of longline catches and troll catches. The longline catches are small both close to land and in the open ocean. For example, Murphy and Shomura (1953*a*, 1953*b*, 1955) and Shomura and Murphy (1955) record only 59 wahoo captured on 14 POFI experimental longline fishing cruises involving numerous stations, some close to land. This figure suggests that wahoo are never abundant at the depths fished by this gear (200–600 ft.). Trolling operations were much more productive, but only close to land. Only 12 wahoo were caught during 5,500 hours of surface trolling in the open sea, more than 60 miles from land (Murphy and Ikehara 1955: 14). In contrast, within a few miles of land in both the Hawaiian Islands and Line Islands surface catches have averaged about 1 wahoo per hour (Table 1). From this information we infer that the wahoo prefer shallow depths and are more abundant close to land.

Even near islands wahoo are not very abundant in the central Pacific. This is suggested by the low catch rates from surface trolling around the Hawaiian and Line islands (Table 1). The troll catches obtained near the Line Islands during all seasons of the year indicate that the species does not occur there in sufficient numbers to support a profitable commercial fishery. This is also true in Hawaii (Welsh 1949*b:* 29). Neither does the wahoo appear to be very abundant in the Atlantic, at least off North Carolina, where Taylor (1951: 278) states that the population is small.

It is interesting to note from the Line Islands data (Table 1) that wahoo and yellowfin tuna, *Neothunnus macropterus* (Temminck and Schlegel), have a similar pattern of seasonal variation in availability. This similarity could indicate that environmental or other factors

TABLE 1

Results of surface trolling for wahoo and yellowfin tuna in waters of the Hawaiian and Line Islands

TIME	HOURS TROLLED	AVERAGE NUMBER OF LINES	WAHOO		YELLOWFIN	
			Number	Catch per hour	Number	Catch per hour
Hawaii						
Year around, 1947–48 (Welsh 1949b)	307	7.0	20	0.07	23	0.08
Line Islands						
April-June 1950 (Bates 1950)	285.5	6.1	178	0.62	882	3.09
March-April 1955	142.5	5.0	274	1.92	438	3.07
May-June 1955	116.0	6.0	135	1.16	100	0.86
July-August 1955	105.0	6.0	83	0.79	24	0.25
September-October 1955	182.0	6.0	245	1.35	171	0.94
November-December 1955	108.0	6.0	144	1.33	64	0.59
January-February 1956	133.5	6.0	267	2.00	148	1.10

influence both species similarly and are of greater importance than inter-specific competition for food, though both appear to feed on similar animals.

REPRODUCTION

In samples from the Line Islands, at all times of the year the percentage of males tends to be higher in the northern islands than in the southern islands (Fig. 2). This consistent trend or gradient suggests a migration of wahoo to maintain itself, unless there is varying differential mortality between sexes among areas, which seems unlikely. Such a gradient might be related to spawning movements but we are unable to describe them.

The wahoo in the Line Islands appear to spawn over an extended period of time, as is common with fish found in tropical waters.

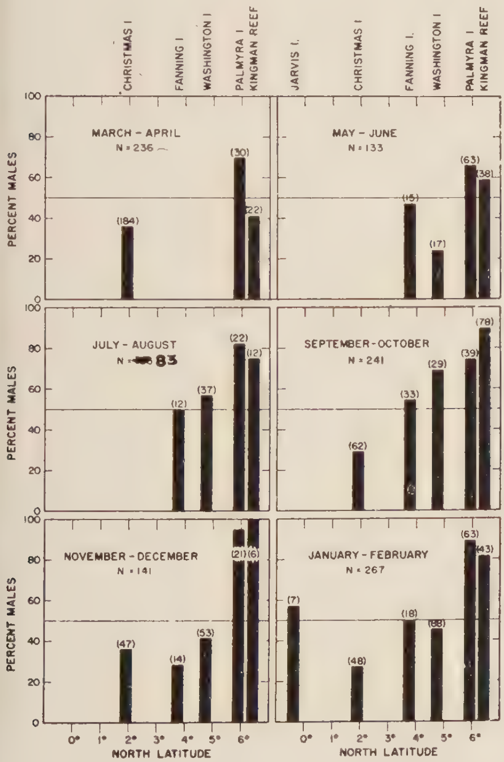

FIG. 2. Percentage of male wahoo by trolling areas, March 1955 to February 1956. (The number in each sample is shown in parentheses).

Cursory field examination of 80 females in March and of 143 in November and December, using categories devised by Marr (1948: 201),—i.e., immature, ripening, ripe, spawning, and spawned out—revealed all stages of maturity during both periods.

In order to estimate the number of eggs per spawning the size frequency distribution of ova in an apparently ripe ovary was determined for a fish of 131 cm. fork length (Fig. 3). Only eggs larger than 8 micrometer divisions, or 0.184 mm., were measured. An abundance of undeveloped or primitive eggs was present in the ovary, but most of these were not measured. The group 0.184–0.46 mm. contained the larger of these "stockpile" eggs; the group from about 0.46 mm. to 0.94 mm., with a prominent mode at 0.62 mm. appeared to be maturing eggs. This latter group of eggs may be likened to the "type B" or developing eggs described by Tester and Takata (1953: 42) from the aholehole, *Kuhlia sandvicensis*. This one specimen showed no clear evidence of more than one mode among the developing eggs. The maturing group of eggs (> 0.46 mm.) in the ovaries of this female wahoo was estimated to number about 6.1 million. This estimate was obtained by weighing the formalin-preserved

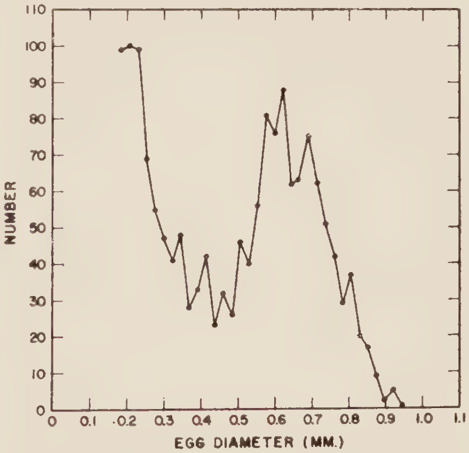

FIG. 3. Frequency distribution of egg diameters from a single female, 131 cm. fork length, captured May 1955 at Fanning Island.

(wet) ovaries, weighing a wedge-shaped section from one of the ovaries, and counting the number of eggs in the most mature group in this sample. The total number of mature eggs in both ovaries was then calculated by simple proportion.

This estimate of 6.1 million eggs per spawning is comparable in order of magnitude to the amount of spawn released by some other related species. Yuen (1955: 18) computed the number of eggs extruded in one spawning of a bigeye tuna, *Parathunnus sibi* (Temminck and Schlegel), in the Pacific to be 2.9 to 6.3 million; June (1953: 63) estimated the number of eggs per spawning of a yellowfin sampled in Hawaii to be 2 to 8 million. Both authors found that the number of eggs spawned increased, in general, with increase in size of fish. This probably holds true for the wahoo.

FOOD HABITS

Of the 235 stomachs examined, 115 (48.5 per cent) were empty. This relatively large number of empty stomachs may be due to regurgitation on capture. The wahoo struggles violently on the trolling line and may regurgitate food while being landed and killed. As some of the stomach contents were probably incomplete, an elaborate analysis of the food based on percentage by volume was not undertaken. Rather the analysis was confined to frequency of occurrence of the various food items.

Fish remains have a high frequency of occurrence among the food items (Table 2), and perhaps beyond their true significance since fish bones are slow to digest and hence persist longer in the stomachs than readily digested items. In both time periods (March, and November–December) mackerel scad, squid, and skipjack appear to be of importance in the food, with mackerel scad being the major item.

A much greater variety of food than is indicated by Table 2 is probably consumed by the wahoo. Very small items could have been overlooked. On infrequent occasions specimens were on deck for several hours prior to the examination of the stomachs, and the

TABLE 2

STOMACH CONTENTS OF 235 TROLL-CAUGHT WAHOO CAPTURED DURING MARCH, AND NOVEMBER-DECEMBER, 1955

FOOD ITEMS	FREQUENCY OF OCCURRENCE		PER CENT FREQUENCY OF OCCURRENCE	
	March	November-December	March	November-December
Items identifiable				
Squid (*Loligo* sp.)	6	3	18.2	13.0
Skipjack (*Katsuwonus pelamis*)	4	6	12.1	26.1
Pomfret (Bramidae)	1	1	3.0	4.4
Puffer (Tetraodontidae)	2	2	6.1	8.7
Mackerel scad (*Decapterus* [*psinnulatus*])	19	9	57.5	39.1
Flying fish (*Cypselurus* sp.)	1	..	3.0	...
Lantern fish (Myctophidae)	..	1	...	4.4
Sunfish (*Ranzania truncata*)	..	1	...	4.4
Total	33	23	99.9	100.1
Entire sample				
Empty stomachs	34	81	39.1	54.7
Fish remains not identifiable	20	44	22.9	29.7
Food remains identifiable	33	23	37.9	15.5
Total	87	148	99.9	99.9

identity of the more readily digestible forms could be lost during this time. Aside from these difficulties, it seems likely that the data in Table 2 provide a reasonably good picture of the food throughout the year. We do not believe there is much seasonal change in the fauna of the tropical Pacific.

The results of other studies suggest the diet of wahoo is similar throughout its range. Welsh (1949*a:* 22) made a preliminary examination of the food of wahoo in the Hawaiian Islands, using a rating system which considered total bulk of food, total number of food items, and the total number of times food was found in individual stomachs. Of the 17 stomachs he examined, 10 were empty. Those containing food held fish and squid. The food habits of the wahoo near Japan would seem to be nearly the same as in the Line Islands, for Kishinouye (1923: 412) states that they "feed on calamaries [squid] and pelagic fish."

LENGTH FREQUENCY ANALYSIS

An examination of the sizes of wahoo in our catches will contribute to our understanding of the biology of this species. In the Line Islands we sampled only a segment of the known size range of the species for small fish were not taken and much larger sizes have been recorded from other areas. Hosaka (1944: 69) reports a 124¾-pound wahoo taken on sport fishing gear off the island of Oahu, and LaMonte (1952: 9) reports a world record for wahoo as 133½ pounds (6 ft., 11 in.) caught in the Bahamas in 1943.

The size distribution of longline-caught wahoo is similar in most respects to that of fish taken on trolling gear. The longline catches, most of which are from the open sea, were made over several years at all months of the year and show a prominent mode at 128 cm. and a lesser mode at 146 cm. (Fig. 4). These fish range from 54 to 198 cm., with the majority between 106 and 162 cm. The measurements of troll-caught wahoo, taken mostly within 3 miles of land, during 1950, 1951, 1955, and 1956 show a similar size range, from 98 to 174 cm., and a similar distribution of sizes. It would appear then that both fishing methods sampled the same segments of a common population.

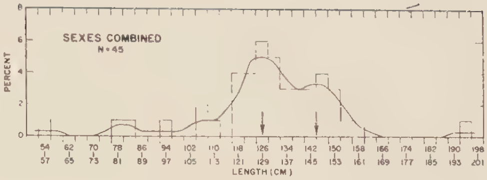

FIG. 4. Size frequency distribution of longline-caught wahoo, October 1950 to March 1955. (Smoothed by a moving average of three.)

Samples of wahoo from some islands show differences in length distribution between sexes. An example of this in distributions of wahoo taken at Christmas Island during March and April 1955 (Fig. 5) shows a slight displacement of modes. In the male distribution there is a small mode at approximately 114 cm. and a dominant mode at approximately 134 cm.; in the female distribution there is a dominant mode at about 128 cm.

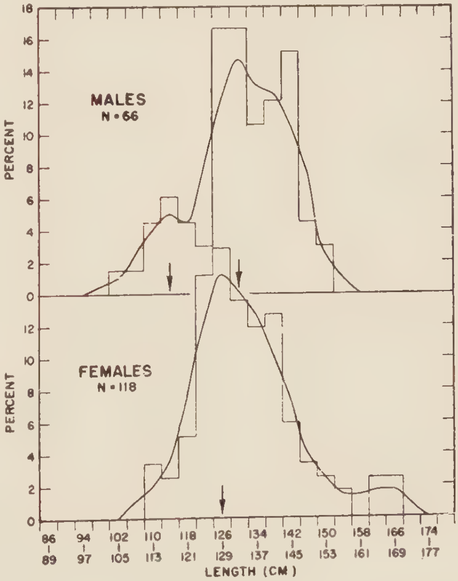

FIG. 5. Size frequency distribution of troll-caught wahoo from Christmas Island during March-April 1955. (Smoothed by a moving average of three.)

and a suggestion of a mode at approximately 164 cm. This suggests a differential growth rate between the sexes.

Wahoo show size variation associated with changes in latitude, as has been described for other scombrid fish. For example, Nakamura (1952: 101) found that the average weight of yellowfin tuna increased with latitude both to the north and south of the equator between the west coast of Sumatra and the Nicobar Islands. With respect to wahoo, the relative abundance of the larger fish appears to decrease from Christmas Island in the south to Palmyra Island and Kingman Reef in the north. This is accompanied by an increase in the numbers of smaller fish from south to north, these trends appearing in both the male and female length distributions (Fig. 6). The indications are that the wahoo are not distributed over the area in random fashion with respect to either size (Fig. 6) or sex (Fig. 2). Unless each area has a separate population with a different growth rate and sex ratio, there must be differential movement of individuals or groups in order to maintain th observed size and sex gradients. This movement, however, need not necessarily be confined to the study area.

This nonrandom distribution of the wahoo makes it almost impossible to study growth by the method of progression of dominant modes in size frequencies because of the great difficulty in obtaining representative samples. Therefore such studies were not attempted.

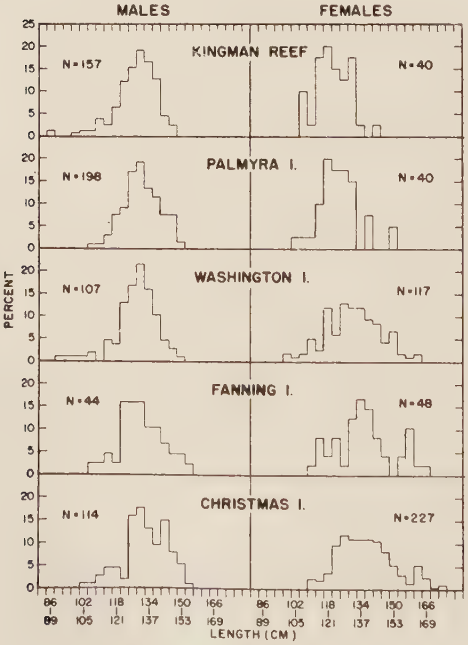

FIG. 6. Length frequency distributions of wahoo by areas, March 1955 through February 1956.

LENGTH-WEIGHT RELATIONSHIP

As no significant difference in the length-weight relationship was noted between sexes, the data were combined to calculate the following regression equation which describes this relationship in the wahoo: Log weight = $-9.4199 + 3.50583$ log length, where weight is in pounds and length in millimeters. The mean weights for given lengths may be determined from the smooth curve shown in Figure 7. This large exponent, 3.50583, reflects the elongate, slender shape of the wahoo. As one would expect for a fish of this shape, a small increase in weight yields a relatively large increase in length. On the other hand

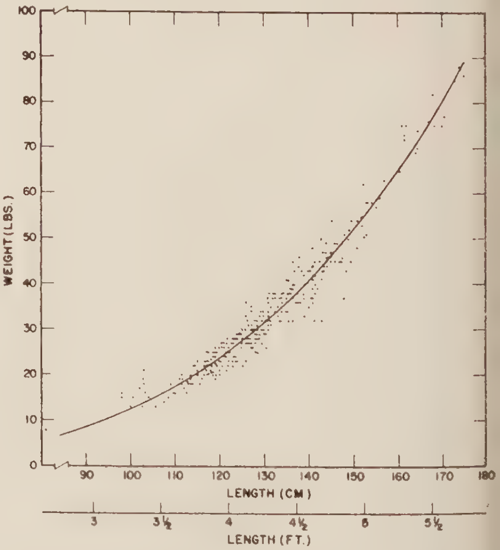

FIG. 7. Length-weight relationship for wahoo from the Line Islands, February 1951 to June 1955. Regression curve fitted by the equation: Log weight = $-9.4199 + 3.50583$ log length.

out-bodied fish, such as some of the tuna, ave a considerably smaller exponent. Exmples are: yellowfin from Costa Rica, which ave an exponent of 2.940 (Schaefer 1948: 19); and bigeye tuna, *Parathunnus sibi* (Teminck and Schlegel), sampled in Hawaii, hich have an exponent of 2.9304 (Iversen 955: 2).

PARASITES

Although no diligent search was made for arasites, the list given in Table 3 indicates at the wahoo is rather heavily parasitized. n the course of the examination of food ems, trematodes about one inch in length hen partially contracted were regularly noted t the posterior end of the stomach. Nigrelli nd Stunkard (1947: 188) have carefully examined the genus *Hirudinella* and, on the basis f 33 specimens taken from wahoo captured n both the Atlantic and Pacific oceans, regard l forms of this giant trematode in the wahoo belonging to a single species, *H. ventricosa* Pallas).

In the 220 stomachs examined during March and November–December 1955 the number of giant trematodes per stomach ranged from 0–17 (Table 4). In all except the largest fish, two trematodes per fish were most commonly encountered, suggesting that this number represents a physiological equilibrium between host and parasite. On the other hand in the largest length group (160–179.9 cm.), four trematodes per stomach were commonly found.

SUMMARY

1. The availability of wahoo caught by trolling and longline fishing indicated the existence in the Line Islands of a small population that was most abundant in shallow water within a few miles of land.
2. Males were relatively more abundant in catches from the more northerly islands than in those from the more southerly islands.
3. Examination of wahoo gonads showed all

TABLE 3
PARASITES OF WAHOO FROM THE LINE ISLANDS, 1955

PARASITE	SITE OF INFECTION	NUMBERS PRESENT PER WAHOO	RATE OF INFESTATION	
			Per cent	Number of wahoo examined
ematoda				
Neothoracocotyle acanthocybii (Meserve)[1]	Between gill filaments	Numerous	(high)	. . .
Didymocystis acanthocybii Yamaguti[1]	Head inside gill covers	Numerous cysts—2 worms/cyst	51.0	104
Hirudinella ventricosa (Pallas)	Caudal end of the stomach	0–17	98.2	220
ematoda	Mass of worms embedded in belly wall	Many	(slight)	. . .
pepoda				
Brachiella sp.	Within joint of pectoral fins	2 in each joint	98.3	118
Gloiopotes sp.	Outside surface of body and caudal fins	Many—variable	54.2	96
Pennella sp.	Embedded in belly wall with hind portion protruding	1 or 2	9.8	92

[1] Trematodes kindly identified by Dr. H. W. Manter, University of Nebraska, Lincoln.

TABLE 4

NUMBER OF GIANT TREMATODES IN STOMACHS OF WAHOO, BY HOST SIZE

NUMBER OF WORMS PRESENT	FREQUENCY OF OCCURRENCE BY HOST SIZE (CM.)							
	100–119.9		120–139.9		140–159.9		160–179.9	
	No.	%	No.	%	No.	%	No.	%
0	..	...	3	2.4	1	1.4	..	...
1	..	...	7	5.7	7	9.7	1	7.7
2	10	90.9	90	72.6	41	56.9	3	23.1
3	..	...	19	15.3	12	16.7	1	7.7
4	1	9.1	3	2.4	8	11.1	6	46.2
5	..	...	1	0.8	1	1.4	1	7.7
6	..	...	1	0.8	..	...	1	7.7
8	..	...	..	...	1	1.4	..	...
17	..	...	..	...	1	1.4	..	...
Total	11	100.0	124	100.0	72	100.0	13	100.1

stages of maturity present. The number of mature eggs in a single female was estimated at over six million.

4. The wahoo taken close to the islands showed little variety in their diet as judged by stomach contents. Of the identifiable food material the main items were mackerel scad, skipjack, and squid.
5. An examination of size frequency distributions from the Line Islands area revealed that the females attain a larger size than the males, and there is some suggestion that the two sexes grow at different rates. No attempt to estimate growth by modal progression is made since there are indications that the samples were not representative of a homogeneous population unit.
6. A length-weight relationship for wahoo from the Line Islands is given by the equation:

   Log weight (pounds) = $-9.4199 + 3.50583$ log length (millimeters).
7. The wahoo was found to be parasitized by trematodes, nematodes, and copepods.

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STRUCTURE AND GROWTH OF SCALES OF YELLOW PERCH OF GREEN BAY

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ABSTRACT

The appearance of the scales of yellow perch differs with the location on the fish's body. Comparison of scales of Green Bay perch taken above and below the lateral line reveals the former to have more sharply defined circuli and to exhibit fewer false annuli and less of the shading that impedes accurate assessment of age.

Estimates of age from modes in length-frequency distributions and from scale readings were the same for age-groups O, I, and II. Older age groups could not be detected in length distributions, but the similarity of all annuli makes it acceptable to conclude that the annulus is in fact a year-mark at ages beyond the II group.

Scales of yellow perch may exhibit new growth in the latter part of May whereas others may not have started growing even in late July. The time of annulus formation varies with calendar year, with age (new growth starts earlier in the younger fish), and possibly with locality. Ages usually can be read from scales collected during the period of annulus formation, but occasionally difficulties are encountered.

For larger yellow perch the relation between fish length and the radius of key scales was described by a straight line with a 2-inch intercept on the length axis when the scales were taken above the lateral line and by a straight line through the origin when the scales came from below the lateral line. Lengths calculated from both relations were inaccurate for small fish. Tables of corrections are given, based on the body-scale curves for small perch.

The body-scale relations (determined from the same key scale) were similar for Lake Erie and Saginaw Bay perch but both differed sharply from the relation in the Green Bay populations.

Good procedure requires high consistency in the field as to the point on the fish's body from which scale samples are taken and also a careful determination of the body-scale relation in each population studied.

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INTRODUCTION

The present paper is another in a series arising from a cooperative study of the Green Bay fisheries initiated in 1948 by the Fish and Wildlife Service and the Wisconsin Conservation Department. Although the Green Bay program has been concerned with various aspects of the fisheries, particular emphasis has been placed on the fishery for yellow perch *(Perca flavescens)*. A statement of the Green Bay perch problem and of changes of regulations based on early findings was given by Hile (1953). Other papers on Green Bay perch dealt with tagging (Joeris, 1953) and movements (Mraz, 1952).

The purposes of this publication are to submit evidence on the validity of the annulus as a true year-mark on the scales of yellow perch in Green Bay, to record information on the time of annulus formation in relation to the determination of age of summer-caught fish, and to show the relationship between fish length and the scale radius of "key" scales from the general areas from which scale samples were removed—in short to establish methods for use in further and detailed studies of regional differences and fluctuations in the perch stocks of Green Bay.

The earlier investigators of the age and growth of yellow perch in the Great Lakes (Harkness, 1922; Jobes, 1933; Hile and Jobes, 1941 and 1942) assumed the validity of the annulus as a year-mark. In his 1952 paper, however, Jobes gave information in support of the dependability of scale readings for yellow perch of Lake Erie. The earliest calculations of past growth from scale measurements (Jobes, 1933—Harkness, 1922, determined ages only) were made by direct proportion. Later calculations for perch of Saginaw Bay (Hile and Jobes, 1941) and Lake Erie (Jobes, 1952) were based on body-scale curves (key scales employed). Because they lacked materials for study of the body-scale relationship in the yellow perch of Green Bay, Hile and Jobes (1942) applied the curve they had derived for Saginaw Bay fish; as will be seen later, the results were not entirely satisfactory.

Investigators of the growth of yellow perch outside the Great Lakes mostly have given only the average sizes of age groups. Schneberger (1935) made direct-proportion calculations of length from measurements of scales of perch from three lakes of northeastern Wisconsin. Carlander (1950) described the body-scale relation of perch from Lake of the Woods with two conic-section parabolas.

MATERIALS AND METHODS

The materials have been selected from extensive collections made in a continuing study of the yellow perch of Green Bay—life history, movements, fluctuations, regional differences, . . .

The 4,070 fish used to illustrate the length-frequency distribution of age-groups (Table 1, see also Fig. 1) were collected with a 42-foot otter trawl, 8 feet deep in the body of the net and 6 feet throughout the wings.

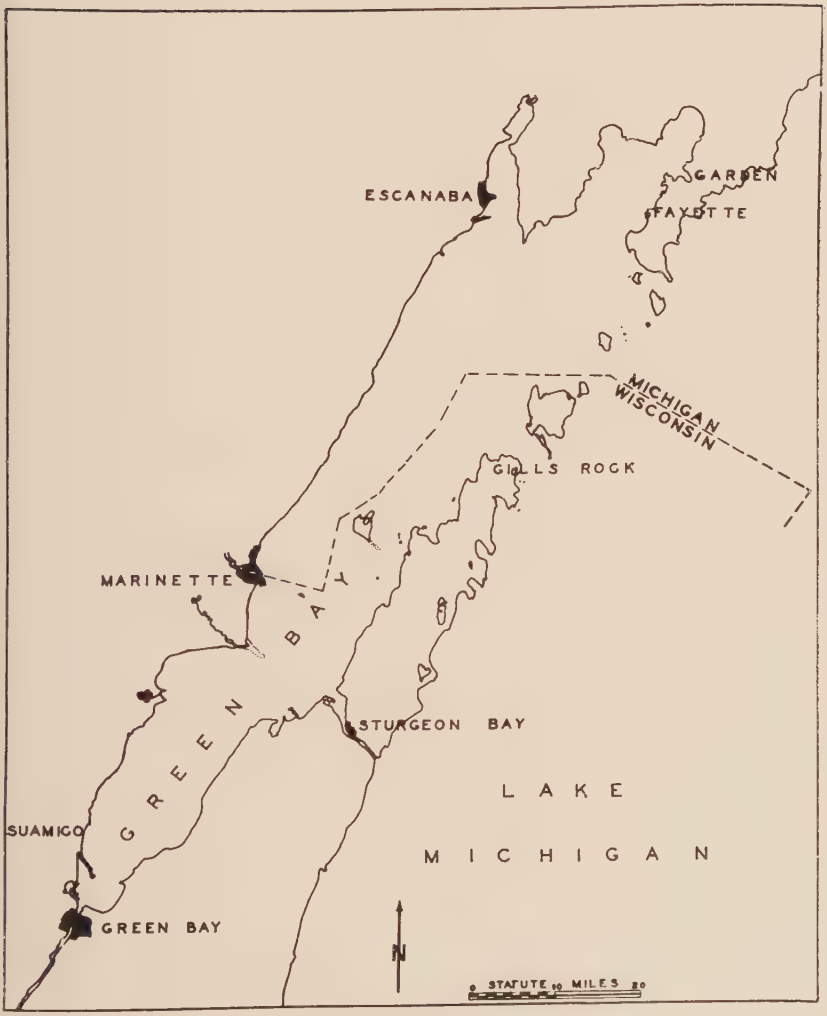

FIGURE 1.—Green Bay region.

The mesh size (extension measure) was 1 inch in the body and wings and ½ inch in the cod end. These three samples are typical of those obtained in trawling operations with the same or similar gear that took a total of more than 12,000 yellow perch.

The individual samples of yellow perch for the study of the body-scale relation (Table 1) were mostly small in order that the entire collection might cover a sufficient range of time and locality to bring out possible variability of the relation. A "key" scale was taken from each fish of each sample—the scale in the second row above the lateral line that fell immediately below the insertion of the first dorsal spine. Key scales from below the lateral line were obtained from the samples of May 27, 1955,

TABLE 1—*Material used for study of the body-scale relationship and length-frenquency distribution of age groups of perch in Green Bay.*

Use of material, gear, and mesh[1]	Date	Location	Number of fish
Length-frequency distribution			
Trawl ½	Oct. 22, 1952	Suamico	1,681
Trawl ½	Oct. 26, 1952	Fayette	670
Trawl ½	Oct. 31, 1953	Fayette	1,719
Body-scale relationship above lateral line			
Wire trap ¾	July 18, 1951	Sturgeon Bay	80
Trap net 2½	Aug. 20, 1951	Sturgeon Bay	15
Pound net 1½	Aug. 22, 1951	Escanaba	47
Dip net ¼	Aug. 29, 1951	Gills Rock	5
Wire trap 1	Sept. 4, 1951	Sturgeon Bay	38
Wire trap ½	Sept. 6, 1951	Gills Rock	4
Wire trap 1	Sept. 10, 1951	Sturgeon Bay	63
Wire trap ¾	Sept. 24, 1951	Sturgeon Bay	34
Fyke net 2⅜	Sept. 25, 1951	Marinette	31
Seine ¼	Sept. 29, 1951	Gills Rock	2
Fyke net 2⅜	Oct. 9, 1951	Suamico	132
Trap net 2	Oct. 9, 1951	Escanaba	8
Fyke net 2⅜	Oct. 10, 1951	Marinette	170
Seine ¼	Oct. 15, 1951	Sturgeon Bay	1
Dip net ¼	Dec. 27, 1951	Green Bay	56
Pound net 1¾	Jan. 22, 1952	Escanaba	75
Trap net 1	May 1, 1952	Sturgeon Bay	23
Fyke net 2	July 3, 1952	Sturgeon Bay	76
Fyke net 2⅜	Oct. 26, 1952	Escanaba	20
Fyke net 2⅜	Nov. 7, 1952	Marinette	23
Body-scale relationship above and below lateral line			
Fyke net 2⅜	May 27, 1955	Suamico	274[2]
Trawl 1½	June 5, 1956	Suamico	10
Seine ¼	June 7, 1956	Gills Rock	38

[1] All mesh sizes are extension measure in inches with the exceptions of wire traps, dip nets, and seines in which bar measurements are given.

[2] Fish in this collection were also used in the comparison of calculated growths from above and below the lateral line.

and June 5 and 7, 1956. This key scale came from the third row below the lateral line directly beneath the sixth spine of the dorsal fin; it is the same key scale that was used by Hile and Jobes (1941) and by Jobes (1952). The reason for the use of two series of key scales is explained in later discussions. Total lengths of all fish were measured on a board and recorded to the nearest 0.1 inch.

The key scales of the samples of July 18, 1951, through November 7, 1952, and June 5 and 6, 1956, were mounted on glass microscope slides in the glycerin-gelatine medium described by Van Oosten (1929). Key scales of the 1955 sample were impressed on cellulose acetate, 0.020 or 0.040 inch thick, by a roller press similar to the one described by Smith (1954). Comparisons of the lengths of key scales (from above the lateral line) of fish of corresponding size as determined from mounts and impressions gave no evidence that method of preparation had any effect on the estimation of scale size. This observation is in agreement with that of Butler and Smith (1953).

The length of each key scale was measured at the magnification x 43 from the center of the focus to the edge of the sculpturing along the middle of the interradial space most nearly collinear with the focus. This measurement was made with a vernier caliper and recorded to the nearest 0.01 inch. Defective scales—regenerated, partially resorbed, or otherwise abnormal—were excluded. Altogether, the key-scale collections included 40 fish with unusable scales; these fish were excluded from the listing of Table 1. The scale length of each fish and accompanying data on fish length, sex, age, and date and locality of collection were punched on IBM cards to facilitate analysis.

The collections selected to show the time of annulus formation in various calendar years are listed in Table 5.

Ages are given in terms of completed years of life. A fish in its first year of life belongs to age-group O, one in its second year to age-group I. . . . Following the recommendation of Hile (1948), each fish is considered to pass into the next higher age group on January 1. Under this convention a "virtual" annulus is accredited at the edge of the scale from the first of the year to the time the annulus is actually formed.

THE YELLOW PERCH SCALE

The scales of yellow perch are typically ctenoid, deeply crenulated, and strongly imbricated. According to the description and diagram of Pycha and Smith (1955), scale pockets first appear in the peduncular region at a fish length of about 20 millimeters. Scale formation proceeds anteriorly along the lateral line and dorsally and ventrally from that line. Some scales are imbricated posteriorly along the lateral line in fish as short as 22 millimeters, and by the time the length has reached 35 millimeters the scales are imbricated over most of the body. This last point was verified by observations on Green Bay perch.

TABLE 2.—*Length-frequency distribution of age groups of yellow perch taken in small-mesh trawls off Fayette, Michigan October 31, 1953.*

[Totals are given for the sexes combined and for the entire collection from which the scale collection was drawn.]

Total length (inches)	Males						Females						Sexes combined	
	0	I	II	III	IV	Total	0	I	II	IV	V	Total	Scale sample	Entire catch
2.2-2.3	..	..	..	..	..	..	..	..	..	..	..	..	..	10
2.4-2.5	4	..	..	..	..	4	4	..	..	..	..	4	8	39
2.6-2.7	6	..	..	..	..	6	7	..	..	..	..	7	13	62
2.8-2.9	11	...	..	..	..	11	15	..	..	..	..	15	26	123
3.0-3.1	18	..	..	..	..	18	10	..	..	..	..	10	28	157
3.2-3.3	17	..	..	..	..	17	7	..	..	..	..	7	24	169
3.4-3.5	2	..	..	..	..	2	2	..	..	..	..	2	4	75
3.6-3.7	5	..	..	..	..	5	1	..	..	..	..	1	6	38
3.8-3.9	..	..	..	..	..	..	3	..	..	..	..	3	3	15
4.0-4.1	..	..	..	..	..	..	1	..	..	..	..	1	1	2
4.2-4.3	..	3	..	..	..	3	..	1	..	..	..	1	4	7
4.4-4.5	..	3	..	..	...	3	..	5	..	..	..	5	8	21
4.6-4.7	..	11	..	..	..	11	..	6	..	..	..	6	17	44
4.8-4.9	..	11	..	..	..	11	..	12	..	..	..	12	23	77
5.0-5.1	..	17	..	..	..	17	..	15	..	..	..	15	32	112
5.2-5.3	..	8	3	..	..	11	..	14	..	..	..	14	25	136
5.4-5.5	..	1	1	..	..	2	..	6	..	..	..	6	8	107
5.6-5.7	..	..	4	..	..	4	..	6	1	..	..	7	11	65
5.8-5.9	..	..	6	..	..	6	..	1	1	..	..	2	8	68
6.0-6.1	..	..	8	..	..	8	..	..	7	..	..	7	15	80
6.2-6.3	..	..	6	..	..	6	..	1	10	..	..	11	17	65
6.4-6.5	..	..	3	..	..	3	..	..	4	..	..	4	7	44
6.6-6.7	..	..	3	1	..	4	..	..	4	..	..	4	8	55
6.8-6.9	..	..	..	..	..	..	..	..	1	..	..	1	1	44
7.0-7.1	..	..	..	1	..	1	..	..	2	..	..	2	3	17
7.2-7.3	..	..	..	..	1	1	..	..	1	..	..	1	2	17
7.4-7.5	..	..	..	..	1	1	..	..	..	..	..	..	1	17
7.6-7.7	..	..	..	..	..	..	..	..	..	..	..	..	..	16
7.8-7.9	..	..	..	1	1	2	..	..	..	..	..	..	2	8
8.0-8.1	..	..	..	..	1	1	..	..	..	..	..	..	1	3
8.2-8.3	..	..	..	..	1	1	..	..	..	1	..	1	2	4
8.4-8.5	..	..	..	..	..	..	..	..	..	1	..	1	1	5
8.6-8.7	..	..	..	..	..	..	..	..	..	..	..	..	..	6
8.8-8.9	..	..	..	..	1	1	..	..	..	1	..	1	2	3
9.0-9.1	..	..	..	..	..	..	..	..	..	2	1	3	3	4
9.2-9.3	..	..	..	..	1	1	..	..	..	1	..	1	2	2
9.4-9.5	..	..	..	..	..	..	..	..	..	..	1	1	1	1
9.6-9.7	..	..	..	..	..	..	..	..	..	..	..	..	..	..
9.8-9.9	..	..	..	..	..	..	..	..	..	..	..	..	..	..
10.0-10.1	..	..	..	..	..	..	..	..	..	1	..	1	1	1
Number......	58	54	34	3	7	161	50	67	31	7	2	157	318	1,719
Average length	3.0	4.8	6.0	7.1	8.2	..	3.0	5.1	6.3	9.0	9.2	..	..	..

On fully scaled yellow perch the appearance of the scale varies from one body region to another, and with this variability are associated important differences in the clarity of the markings employed for age determination. Perch scales collected from Green Bay before June 1950 were taken below the lateral line in the area of the second key scale defined in the preceding section. Beginning in June 1950 the scales were taken from the key area above the lateral line. Comparisons of scales from above and below the lateral line of the same fish (Fig. 2) illustrate differences between the two areas and justify a change in the point of removal of scales.

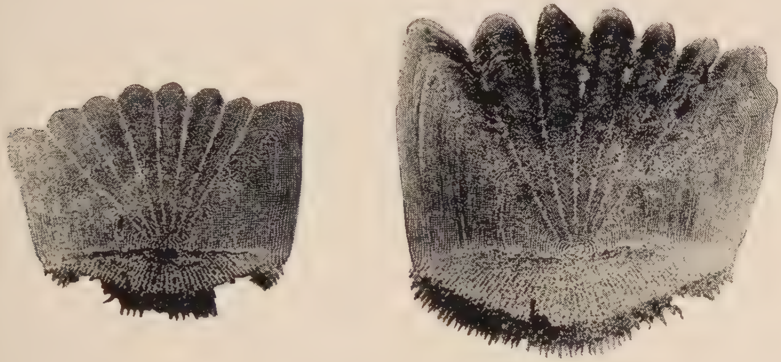

FIGURE 2.—Comparison of perch scales from two positions on the same fish, above lateral line (at left) and below lateral line (at right). Length of fish, 7.4 inches; age-group III.

The principal advantages of the scales from above the lateral line over those from below the lateral line may be summarized as follows:

1. Scales above the lateral line are relatively small and thin, and hence transmit light readily to give a clearly visible image. This advantage over scales below the lateral line grows increasingly important as the fish become larger.

2. The scales above the lateral line have the more sharply defined circuli. They are seldom broken or irregular. On scales below the lateral line, circuli are often "wavy" and commonly are interrupted and fused to neighboring circuli to give branched structures.

3. "Shading"—light and dark bands that bear no fixed relation to annuli—is less frequent and less pronounced on scales above the lateral line. The scale from a VI-group fish in Figure 4 gives an example of clear markings at a relatively advanced age. On scales below the lateral line this shading together with reduced light transmission can make the scales of the larger, older fish most difficult to read.

4. Accessory checks or "false annuli" are less frequent and less pronounced on the scales above the lateral line.

The single disadvantage in scales above the lateral line is the occasionally weak definition of the first annulus. With experience, errors from this difficulty can be avoided.

The differences between scales above and below the lateral line are probably of greater consequences in the slowly growing Green Bay stock than in many, possibly most, other populations in the Great Lakes. Determination of age from scales of yellow perch of this bay must be recognized as difficult. In the rapidly growing perch studied by Hile and Jobes (1940) and Jobes (1953) scales below the lateral line seem to have been fully satisfactory.

VALIDITY OF THE ANNULUS

The principal evidence offered here on the validity of the annulus as a year-mark on the scales of yellow perch of Green Bay is the agreement between ages as read from scales and as estimated from modes in the length-frequency distributions of large samples of fish[1]. Although this method is applicable only to those younger age groups that stand out in a general length distribution, it has the great advantage of being direct. Since the appearance of the annuli at the lesser ages is similar to that of the later annuli of older fish, a reasonable extension of conclusions based on the younger fish is acceptable. As the study of Green Bay perch is continued, additional evidence on the validity of the annulus almost surely will accumulate.

All of the length-frequency distributions of yellow perch captured on Green Bay by small-mesh otter trawls were multi-modal (Tables 2, 3, and 4; Figs. 5, 6, and 7.) The length distributions of both male and female perch of the October 1953 sample from Fayette, Michigan, exhibited three distinct modes that strongly suggest the presence of three age-groups[2]. This view was supported fully by the scale readings. For males the modes (from length frequencies, original data compiled by 0.1 inch groups) and mean lengths (from scale readings) were: age-group O, 3.1 and 3.0 inches; age-group I, 5.1 and 4.8 inches; age-group II, 6.1 and 6.0 inches. For the females the modes and means were: age-group 0, 2.9 and 3.0 inches; age-group I, 5.1 and 5.1 inches; age-group II, 6.3 and 6.3 inches. This close agreement between estimates from length distributions and from scales (see Fig. 4 for typical scales from fish of age-groups O, I and II) leaves no doubt that scales of young of the year lacked annuli

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[1] For reviews of the various kinds of evidence that have been offered in support of the validity of scale readings see papers by Van Oosten (1929) and Hile (1941).

[2] Frequency distributions are given in the tables for the sexes combined (scale sample) and for the entire catch to demonstrate that the subsamples from which scales were taken were satisfactorily representative.

TABLE 3.—*Length-frequency distribution of age groups of yellow perch taken in small-mesh trawls off Fayette, Michigan October 22, 1952.*

[Totals are given for the sexes combined and for the entire collection from which the scale collection was drawn.]

Total length (inches)	Males							Females						Sexes combined	
	0	I	II	III	IV	V	Total	0	I	II	III	IV	Total	Scale sample	Entire catch
2.0-2.1	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	1
2.2-2.3	. .	. .	. .	.	. .	. .	.	. .	. .	. .	. .	. .	. .	. .	. .
2.4-2.5	2	. .	. .	. .	. .	. .	2	4	. .	. .	. .	. .	4	6	16
2.6-2.7	3	. .	. .	. .	. .	. .	3	5	. .	. .	. .	. .	5	8	23
2.8-2.9	4	. .	. .	. .	. .	. .	4	4	. .	. .	. .	. .	4	8	20
3.0-3.1	1	. .	. .	. .	. .	. .	1	1	. .	. .	. .	. .	1	2	9
3.2-3.3	1	. .	. .	. .	. .	. .	1	1	. .	. .	. .	. .	1	2	5
3.4-3.5	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	2
3.6-3.7	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .
3.8-3.9	. .	. .	. .	. .	. .	. .	. .	. .	1	. .	. .	. .	1	1	2
4.0-4.1	. .	. .	. .	. .	. .	. .	. .	. .	1	. .	. .	. .	1	1	7
4.2-4.3	. .	3	. .	. .	. .	. .	3	. .	1	. .	. .	. .	1	4	17
4.4-4.5	. .	9	. .	. .	. .	. .	9	. .	5	. .	. .	. .	5	14	40
4.6-4.7	. .	9	. .	. .	. .	. .	9	. .	9	. .	. .	. .	9	18	58
4.8-4.9	. .	8	. .	. .	. .	. .	8	. .	13	. .	. .	. .	13	21	51
5.0-5.1	. .	11	. .	. .	. .	. .	11	. .	11	. .	. .	. .	11	22	41
5.2-5.3	. .	4	. .	. .	. .	. .	4	. .	7	. .	. .	. .	7	11	18
5.4-5.5	. .	1	. .	. .	. .	. .	1	. .	. .	. .	. .	. .	. .	1	9
5.6-5.7	. .	1	1	. .	. .	. .	2	. .	. .	. .	. .	. .	. .	2	7
5.8-5.9	. .	1	1	2	. .	. .	4	. .	. .	1	. .	. .	1	5	6
6.0-6.1	. .	. .	3	. .	. .	. .	3	. .	. .	. .	. .	. .	. .	3	7
6.2-6.3	. .	. .	3	3	. .	. .	6	. .	. .	1	1	. .	2	8	13
6.4-6.5	. .	. .	4	13	. .	. .	17	. .	. .	1	1	. .	2	19	26
6.6-6.7	. .	. .	. .	19	. .	. .	19	. .	. .	1	. .	. .	1	20	34
6.8-6.9	. .	. .	1	31	. .	. .	32	. .	. .	. .	2	. .	2	34	43
7.0-7.1	. .	. .	. .	17	1	. .	19	. .	. .	1	. .	. .	1	28	28
7.2-7.3	. .	. .	. .	19	. .	1	20	. .	. .	. .	1	1	2	21	30
7.4-7.5	. .	. .	. .	12	3	. .	15	. .	. .	. .	12	. .	12	27	44
7.6-7.7	. .	. .	. .	7	1	. .	8	. .	. .	. .	11	. .	11	19	26
7.8-7.9	. .	. .	. .	. .	2	. .	2	. .	. .	1	9	. .	10	12	22
8.0-8.1	. .	. .	. .	3	1	. .	4	. .	. .	. .	3	. .	3	7	12
8.2-8.3	. .	. .	. .	1	2	. .	3	. .	. .	. .	6	. .	6	9	10
8.4-8.5	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	4	. .	4	4	8
8.6-8.7	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	4	1	5	5	9
8.8-8.9	. .	. .	. .	. .	1	. .	1	. .	. .	. .	4	1	5	6	9
9.0-9.1	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	6	2	8	8	10
9.2-9.3	. .	. .	. .	. .	1	. .	1	. .	. .	. .	. .	. .	. .	1	2
9.4-9.5	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	1	. .	1	1	1
9.6-9.7	. .	. .	.	. .	. .	. .	.	. .	. .	.	. .	. .	. .	. .	. .
9.8-9.9	. .	. .	. .	. .	. .	. .	. .	. .	.	. .	2	. .	2	2	2
10.0-10.1	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	1
10.2-10.3	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .
10.4-10.5	. .	. .	. .	. .	. .	1	1	. .	. .	.	. .	. .	. .	1	1
Number....	11	47	13	127	12	2	212	15	48	6	67	5	141	353	670
Aver. lgth..	2.8	4.9	6.3	9.1	8.0	8.8	. .	2.8	4.9	6.7	8.0	8.6	. .	. .	. .

and that the annuli on the scales of fish assigned to age-groups I and II were in fact year-marks. In view of the similarity of these earlier, valid annuli to the later ones on presumably older fish (for example, age-groups III and VI, Fig. 4) it appears safe to assume that these later annuli also are year-marks.

The October 1953 sample from Fayette was peculiarly well suited to show agreement between ages as estimated from modes and as read from scales because of the scarcity of III-group fish (the females included no members of this age group). Had the III group been better represented in comparison with age-group II, the mode for perch of the latter age would not have stood out so sharply in the general distribution. The importance of the relative numbers in age groups to the appearance of the length distribution is brought out by the data on the Fayette samples of October 1952 (Table 3; Fig. 6). Here age-group O (despite its limited representation) and age-group I appear as distinct modes in the length distribution of each sex. However, the third mode which, in the absence of other information, probably would be taken to represent age-group II was indicated by scale readings actually to represent the III groups.

This seeming conflict between length distribution and scale readings does not damage the argument as to the validity of the annulus as a year-mark. On the contrary, the 1952 and 1953 samples from Fayette, considered together, offer the strongest evidence of another type that scale readings are highly dependable. The poorly represented age groups, the II group of 1952 and the III group of 1953, both came from the 1950 hatch. Inasmuch as this year class was indicated to be extremely weak in two independent estimates made 1 year apart, we may conclude that its members laid down a single annulus during the year between samplings.

The third trawl sample, the one collected off Suamico, Wisconsin, in October 1952, serves principally to show a general similarity of length distributions in southern and northern Green Bay (Table 4; Fig. 7). In the Suamico collection, age-groups O and I stood out as distinct modes, but the II group did not, largely because of the presence of relatively good numbers of age-group III, the broad range of length in both age groups, and the small difference between their average lengths.

The evidence on the validity of annuli as year-marks does not warrant the conclusion that the scales of every fish are read correctly. Accessory checks or false annuli can occur which resemble the true annulus so closely as to deceive the investigator. Furthermore, the scales of some fish exhibit such a confused and irregular pattern as to make the actual age uncertain. Nevertheless, the general dependability of age determination from scales can be accepted and the method may be applied with a high level of confidence to the study of the life history of the yellow perch of Green Bay.

TIME OF ANNULUS FORMATION

The formation of annuli on the scales of a stock of fish ordinarily takes place over a considerable period of time—at least several weeks. The actual dates vary with species, among different stocks of the same species, and from year to year, and according to age within a single stock[3]. This variability can lead to difficulties in age determination in samples collected during the period of annulus formation. Usually it is possible to judge with confidence whether an individual fish has started the current season's growth, but if the period of annulus formation is long and if growth is slow or variable it may be difficult sometimes to judge whether the scale margin outside the last visible annulus represents exceptionally good growth in the current year (after completion of annulus) or relatively poor growth in the preceding year (annulus not yet completed). Hile (1941), for example, rejected a sample of rock bass *(Ambloplites rupestris)* taken from Nebish Lake, (Wisconsin) on July 5 and 6, 1930, because he could not decide for certain fish ". . . whether the band of growth represented growth made in 1930 subsequent to annulus formation or whether the 1930 annulus had not yet been formed . . .".

To estimate the length of time over which Green Bay yellow perch form annuli and especially to learn whether difficulties of age determination might exist similar to those described by Hile for the Nebish Lake rock bass, a tabulation was made of the incidence of new (current-season) growth on the scales of fish collected in spring and early summer. Before this material is discussed, some comments are needed on the course of early-season growth and on the criterion used for decision as to whether new growth had started. The first evidence of resumption of scale growth is seen in the broadening of the clear, unsculptured margin of the anterior field. The width of this margin is so variable, however, that it cannot provide a usable basis for decision. In the preparation of Table 5 a scale was considered to show new growth when at least one new circulus was completed across the anterior edge to make at least a start on the "line of discontinuity" which, when carried laterally to the posterior field, would constitute a completed annulus (Fig. 3). Although this criterion seemed the most satisfactory, its application is not without danger. It is possible that on a few scales the apparent "new growth" merely resulted from a check laid down near the end of the preceding season—a check that could be detected readily once the true annulus was completed. On the other hand, it does not seem desirable to hold that new growth has not started until the annulus is complete. Typically a considerable amount of growth has been made anteriorly by the time new growth first becomes visible in the postero-lateral field (Fig. 3).

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[3] See Beckman (1943) for a review of the literature on annulus formation.

TABLE 4.—*Length-frequency distribution of age groups of yellow perch taken in small-mesh trawls off Suamico, Wisconsin October 22, 1952.*

[Totals are given for the sexes combined and for the entire collection from which the scale collection was drawn.]

Total length (inches)	Males					Females						Sexes combined	
	0	I	II	III	Total	0	I	II	III	IV	Total	Scale sample	Entire catch
2.4-2.5	..	..	..	..	..	..	..	..	..	..	..	..	1
2.6-2.7	..	..	..	..	..	..	..	..	..	..	..	..	.
2.8-2.9	3	..	..	..	3	1	..	..	..	..	1	4	8
3.0-3.1	5	..	..	..	5	10	..	..	..	..	10	15	33
3.2-3.3	5	..	..	..	5	13	..	..	..	..	13	18	70
3.4-3.5	3	..	..	..	3	8	..	..	..	..	8	11	58
3.6-3.7	..	..	..	..	..	4	..	..	..	..	4	4	25
3.8-3.9	..	..	..	..	..	..	..	..	..	..	..	..	8
4.0-4.1	..	..	..	..	..	..	..	..	..	..	..	..	
4.2-4.3	..	1	..	..	1	..	..	..	..	..	..	1	3
4.4-4.5	..	2	..	...	2	..	1	..	..	..	1	3	12
4.6-4.7	..	10	..	..	10	..	4	..	..	..	4	14	32
4.8-4.9	..	20	..	..	20	..	18	..	..	..	18	38	126
5.0-5.1	..	29	..	..	29	..	20	..	..	..	20	49	237
5.2-5.3	..	11	3	..	14	..	24	..	..	..	24	38	235
5.4-5.5	..	5	..	..	5	..	4	..	..	..	4	9	163
5.6-5.7	..	1	2	..	3	..	1	1	..	..	2	5	91
5.8-5.9	..	2	2	..	4	..	1	4	..	..	5	9	49
6.0-6.1	..	..	7	1	8	..	1	..	..	..	1	9	43
6.2-6.3	..	..	11	2	13	..	..	4	..	..	4	17	55
6.4-6.5	..	..	4	5	9	..	..	1	..	..	1	10	63
6.6-6.7	..	..	6	5	11	..	..	1	..	..	1	12	66
6.8-6.9	..	..	6	4	10	..	..	3	1	..	4	14	83
7.0-7.1	..	..	..	7	7	..	..	3	..	..	3	10	72
7.2-7.3	..	..	..	3	3	..	..	..	2	1	3	6	40
7.4-7.5	..	..	..	2	2	..	..	2	2	..	4	6	47
7.6-7.7	..	..	..	1	1	..	..	..	1	..	1	2	24
7.8-7.9	..	..	..	..	..	..	..	..	1	..	1	1	12
8.0-8.1	..	..	..	1	1	..	..	..	..	..	..	1	7
8.2-8.3	..	..	..	..	..	..	..	..	..	..	..	..	10
8.4-8.5	..	..	..	..	..	..	..	..	..	..	..	..	4
8.6-8.7	..	..	..	..	..	..	..	..	1	..	1	1	1
8.8-8.9	..	..	..	..	..	..	..	..	..	..	..	..	1
9.0-9.1												.	
9.2-9.3													
9.4-9.5	..	..	..	..	.	..	..	..	..	..	..	..	1
9.6-9.7											.	.	.
9.8-9.9	..	..	..	..	..	..	..	..	..	..	..	..	1
Number	16	81	41	32	169	36	74	19	8	1	138	307	1,681
Average length	3.1	5.0	6.3	6.8	..	3.3	5.1	6.5	7.6	7.2	..	..	..

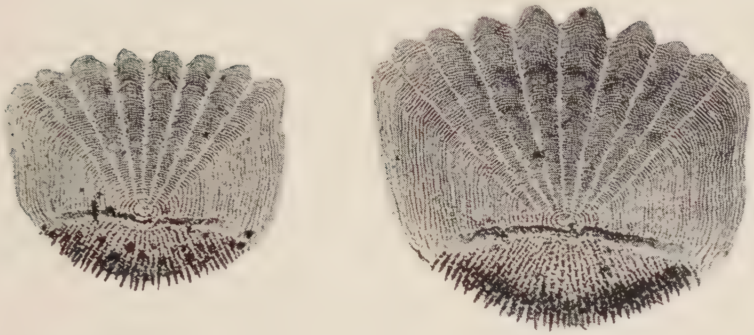

FIGURE 3.—Annulus formation on the scale of yellow perch. Current-season growth has not started on the scale at the left; the appearance is typical of scales collected in late fall or early spring. New growth has started on the scale at right; 3-4 circuli are visible anteriorly but the new annulus is not quite complete in the lateral fields.

The one April sample of yellow perch from Green Bay (April 30, 1951) included no fish that had started new growth (Table 5).

The May collections of 1949-1954 included a scattered few yellow perch (most in age-groups II and III) whose scales gave indication of new growth. In the nine samples obtained in those years the incidence of new growth ranged from nil in the two collections of May 21, 1954, to 5 percent in that of May 10, 1949. Some of these fish actually may have started to grow; on others the difficult marginal scale pattern may have been misinterpreted.

The 1955 sample differed from the May collections of earlier years in that a good majority (69 percent of the total; 20-100 percent in individual age groups) exhibited new growth. The incidence of new growth decreased from age-group II through age-group V, but increased slightly in the VI group. This early start most probably was caused by the exceptionally warm spring. According to records of the U.S. Weather Bureau the plus departures of the 1955 air temperature at Green Bay and Escanaba from monthly normals for April and May were:

City	*Departure from normal temperature (F°)*	
	April	*May*
Green Bay	7.1	2.4
Escanaba	7.3	3.8

Only three samples were collected in June. Two from Marinette (June 25, 1950, and June 2, 1953) included few fish whose scales exhibited new growth. In the sample from Garden (June 6. 1953) 39 percent had started to grow. The difference between the Marinette sample of June 2 and the Garden sample of June 6, suggests possible local vari-

TABLE 5.—*Percentage of yellow perch in the different age groups of various collections whose scales indicated that the current-season growth had started.*

[In parenthesis, number with new growth at left and number without new growth at right; gear of capture as follows: pound-net—April 30, 1951; otter trawl—May 31 and June 24, 1952—first sample May 21, 1954; fyke-net—all other samples.]

Date of Collection	Port	Age group								
		I	II	III	IV	V	VI	VII	VIII	All ages
1949										
May 10	Suamico	. .	. .	7	2	3	0	. .	. .	5
		. .	. .	(7-94)	(1-63)	(1-37)	(0-3)	. .	. .	(9-197)
May 17	Suamico	. .	. .	20	0	0	0	0	. .	4
		. .	. .	(3-12)	(0-22)	(0-34)	(0-11)	(0-2)	. .	(3-81)
1950										
May 10	Suamico	. .	. .	9	0	0	0	0	. .	2
		. .	. .	(5-52)	(0-108)	(0-48)	(0-8)	(0-4)	. .	(5-220)
June 25	Marinette	. .	. .	14	8	0	. .	. .	. .	4
		. .	. .	(1-6)	(3-34)	(0-57)	. .	. .	. .	(4-97)
July 14	Suamico	. .	100	67	[1] . .	[1] . .	. .	. .	. .	[1]
		.	(6-0)	(10-5)						
1951										
April 30	Suamico	0	0	. .	. .	. .	. .	. .	. .	0
		(0-81)	(0-5)	. .	. .	. .	. .	. .	. .	(0-86)
May 10	Suamico	. .	. .	6	2	1	0	. .	. .	2
		. .	. .	(3-51)	(2-123)	(1-69)	(0-11)	. .	. .	(6-254)
July 18	Suamico	. .	100	100	100	. .	. .	. .	. .	100
		.	(5-0)	(41-0)	(7-0)	. .	. .	. .	. .	(53-0)
1952										
May 31	Marinette	0	0	8	1	0	0	. .	. .	2
		(0-15)	(0-3)	(3-33)	(1-131)	(0-10)	(0-6)	. .	. .	(4-198)
July 24	Marinette	100	27	31	38	100	. .	. .	. .	39
		(5-0)	(3-8)	(10-22)	(3-5)	(1-0)	. .	. .	. .	(22-35)
1953										
May 26	Suamico	. .	0	3	8	0	0	. .	. .	3
		. .	(0-1)	(1-30)	(3-34)	(0-58)	(0-2)	. .	. .	(4-125)
June 2	Marinette	. .	. .	0	0	1	0	0	0	1
		. .	. .	(0-2)	(0-37)	(1-69)	(0-8)	(0-2)	(0-1)	(1-119)
June 6	Garden	. .	. .	100	44	17	0	. .	. .	39
		. .	. .	(1-0)	(44-57)	(2-10)	(0-5)	. .	. .	(47-72)
1954										
May 10	Marinette	. .	50	0	0	0	0	. .	. .	1
		. .	(1-1)	(0-59)	(0-16)	(0-58)	(0-11)	. .	. .	(1-145)
May 21	Suamico	0	0	0	0	0	. .	. .	. .	0
		(0-2)	(0-81)	(0-61)	(0-3)	(0-5)	. .	. .	. .	(0-152)
May 21	Suamico	. .	. .	0	0	0	0	0	0	0
		. .	.	(0-77)	(0-31)	(0-36)	(0-11)	(0-11)	(0-1)	(0-167)
July 22	Marinette	.	100	100	100	100	100	. .	. .	100
		. .	(9-0)	(79-0)	(14-0)	(23-0)	(6-0)	. .	. .	(131-0)
July 23	Suamico	. .	100	100	100	100	. .	. .	. .	100
			(58-0)	(86-0)	(5-0)	(5-0)	. .	. .	. .	(154-0)
July 26	Garden	. .	. .	100	100	100	100	. .	. .	100
		. .	. .	(83-0)	(24-0)	(130-0)	(5-0)	. .	. .	(242-0)
1955										
May 27	Suamico	. .	100	90	39	20	44	. .	. .	69
			(19-0)	(128-14)	(36-57)	(2-8)	(4-5)	. .	. .	(189-84)

[1] Age uncertain for most older fish.

ation in the time of onset of new growth. The Garden sample and the 1950 collection from Marinette indicated an earlier start of new growth among the younger than among the older fish.

All of the yellow perch had started current-season growth in four of the six July samples. These four collections were made from July 18 (Suamico, 1951) to July 26 (Garden, 1954). Only 39 percent, however, had begun to grow in the Marinette sample of July 24, 1952. The difference between the 1952 and 1954 collections from Marinette offers another example of annual variation in the date of onset of growth. The 1952 sample from Marinette exhibited no clear-cut relation between age and the start of growth.

The sample of July 14, 1950, requires special comment since it was the only one in which the assessment of age was difficult for a high percentage of the fish. In other samples the distribution of the width of the bands of marginal growth was such that only rarely was it difficult to decide whether the band represented current-season growth or the entire growth of the preceding season. Some errors may have been made, but surely they were few. It is believed that in the sample of July 14, 1950, the members of age-groups II and III were identified correctly, but among

TABLE 6.—*Scale radius* (S) *at different fish lengths* (L) *and variation of the body-scale ratio with increase of length for key scales above and below the lateral line.*

	Above lateral line				Below lateral line			
Total length (inches)	Number of fish	Average total length (inches)	Average scale radius (inches x 43)	L / S	Number of fish	Average total length (inches)	Average scale radius (inches x 43)	L / S
2.5-2.9	6	2.87	0.68	4.22	6	2.87	1.13	2.54
3.0-3.4	10	3.19	0.83	3.84	10	3.19	1.38	2.31
3.5-3.9	14	3.72	1.09	3.41	14	3.72	1.71	2.18
4.0-4.4	9	4.11	1.29	3.19	9	4.11	2.18	1.89
4.5-4.9	2	4.65	1.45	3.21	2	4.65	2.34	1.99
5.0-5.4	45	5.28	1.92	2.75	7	5.27	2.94	1.79
5.5-5.9	68	5.71	2.14	2.67	7	5.69	3.62	1.57
6.0-6.4	67	6.19	2.51	2.47	11	6.21	4.06	1.53
6.5-6.9	60	6.74	2.88	2.34	48	6.76	4.50	1.50
7.0-7.4	118	7.21	3.07	2.35	113	7.22	4.58	1.58
7.5-7.9	98	7.66	3.26	2.35	80	7.64	4.85	1.58
8.0-8.4	40	8.14	3.62	2.25	13	8.13	5.21	1.56
8.5-8.9	24	8.68	4.03	2.15	3	8.60	5.25	1.64
9.0-9.4	23	9.21	4.20	2.19	6	9.20	5.98	1.54
9.5-9.9	20	9.60	4.72	2.03	2	9.85	6.62	1.49
10.0-10.4	23	10.19	5.12	1.99	1	10.30	7.05	1.46
10.5-10.9	24	10.65	5.26	2.02	..	..		
11.0-11.4	18	11.16	5.43	2.06				
11.5-11.9	15	11.69	5.96	1.96	..			
12.0-12.4	8	12.10	6.04	2.00	..			
12.5-12.9	6	12.72	6.32	2.01	..			
13.0-13.4	6	13.13	6.30	2.08				
13.5-13.9	4	13.72	6.68	2.05				
14.0-14.4	2	14.00	6.10	2.30				

older fish the interpretation of marginal growth was uncertain on so many scales that separation into age-groups was inadvisable. No explanation can be offered now for this peculiarity of the sample.

Despite the variability in the data as to the start of growth of yellow perch in Green Bay, certain general statements can be made. Normally the scales of relatively few perch collected before the end of May give evidence of current-season growth, but in exceptional years (as 1955) a large percentage of the fish may be growing before the end of the month. Perch showing new growth may still be scarce in late June (only 3 percent on June 25, 1950) and good numbers may have started growth in early June (39 percent on June 6, 1953). All perch had started to grow in four of the collections made in the last half of July, but only 39 percent showed new growth in the Marinette collection of July 24, 1952. All perch collected in August (data not tabulated in Table 5) had completed annuli. The onset of the season's growth varies with age (is earlier in the younger fish), calendar year, and possibly with locality. Ages can be read with confidence from most scales collected during the period of annulus formation, but in the exceptional collection age determinations may be uncertain for many of the older fish (samples of July 14, 1950).

BODY-SCALE RELATION

At the time the field station of Great Lakes Fishery Investigations was established at Sturgeon Bay, Wisconsin, in June 1950, only limited progress had been made on the study of materials collected from Green Bay in 1948, 1949, and May 1950. The urgency of keeping abreast of changing conditions in the Bay was so great that these earlier samples continued to be neglected during the next several years, while efforts were concentrated on the immediate study of current samples.

As part of the program that started in 1950, materials were collected for study of the relation between length of fish and the radius of key scales from the region above the lateral line from which scale samples were removed after May 1950. These collections were made July 18, 1951, to November 7, 1952 (Table 1). Because Hile and Jobes (1942) had applied the body-scale curve for perch from Saginaw Bay to the Green Bay fish, no key scales were collected from the region below the lateral line from which earlier scale samples had been removed. When the study of the 1948, 1949, and May 1950 materials was started it became obvious at once that the Saginaw Bay curve did not give satisfactory results with those Green Bay materials. Key scales from above and below the lateral line were accordingly obtained from samples collected May 27, 1955, and June 5 and 7, 1956.[4]

The scale samples collected on June 5 and 7, from fish with total length of 2.8 to 5.5 inches were applied to complete the lower portions of both curves.

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[4] Key scales taken above the lateral line on May 27, 1955, were used to compare growth histories of the same fish as computed from measurements of scales from two locations on the body and for comparing estimates of scale size as determined from glycerin-gelatine mounts and from plastic impressions.

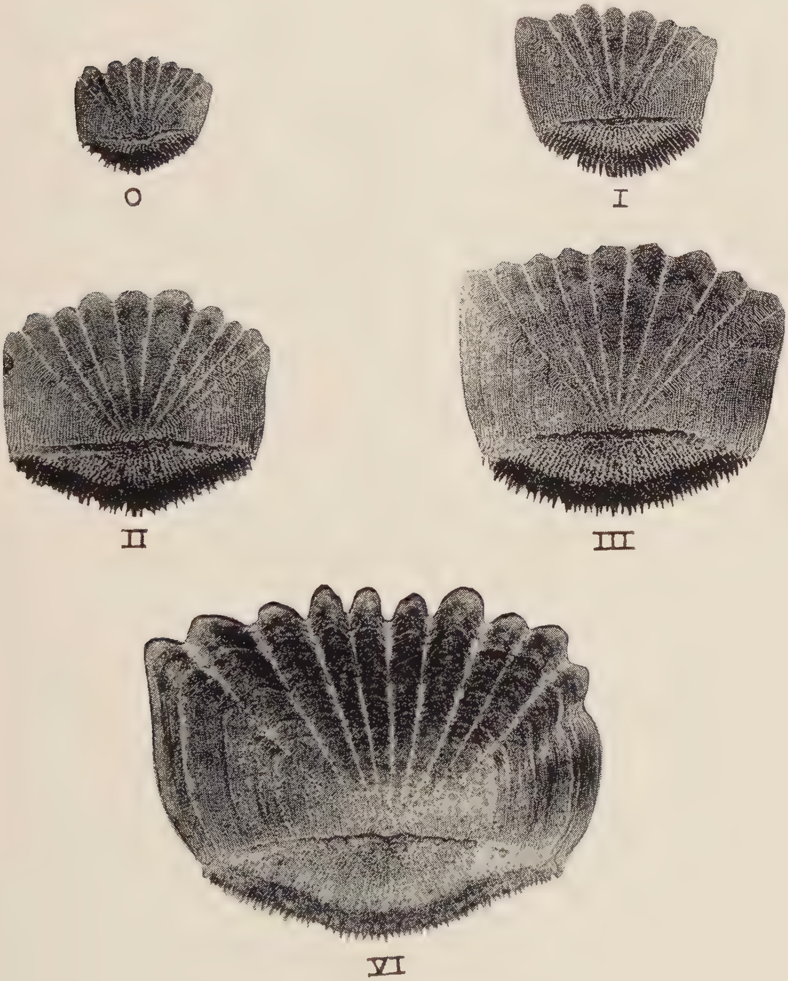

FIGURE 4.—Typical scales of yellow perch of age-groups O, I, II, III and VI.

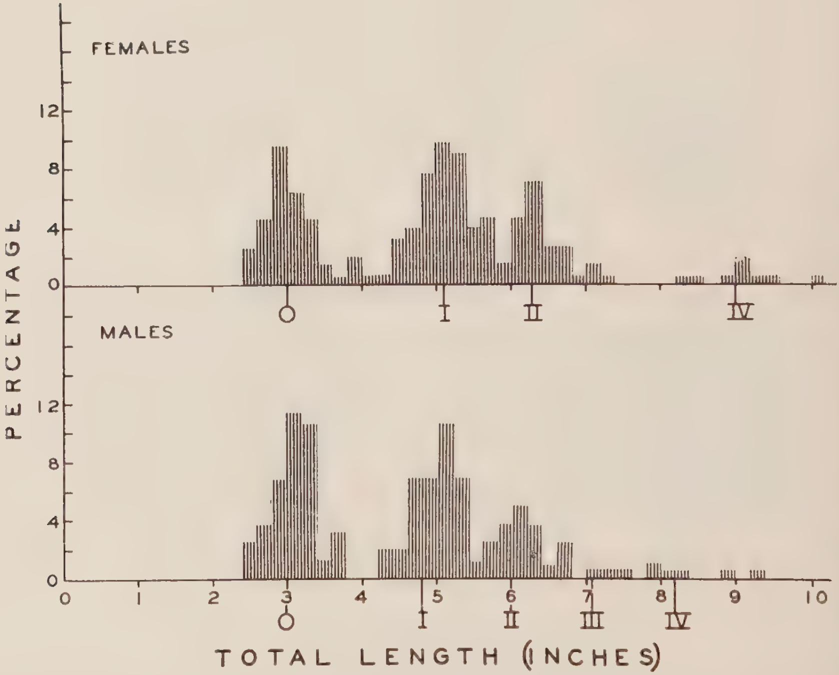

FIGURE 5.—Length distribution of yellow perch taken by trawl off Fayette, Michigan, October 31, 1953. Average lengths of age groups as read from scales are indicated.

KEY SCALES ABOVE THE LATERAL LINE

Preliminary analyses indicated that among fish of the same length, the radius of the scale did not vary significantly with age, sex, locality, or date of capture. All samples, therefore, were combined for further study of the body-scale relation. A graph of the average length of scales for 0.1-inch intervals of fish length (Fig. 8; these data are summarized by 0.5-inch intervals of length in Table 6) indicated the body-scale relation of yellow perch 4.0 to 14.0 inches long could be described by a straight line. The equation for this line, fitted by least squares, was

$$L = 1.980 + 1.687\ S$$

where L equals total length in inches, and S equals scale radius (x 43) in inches. For practical purposes the intercept may be taken as 2.0 inches.

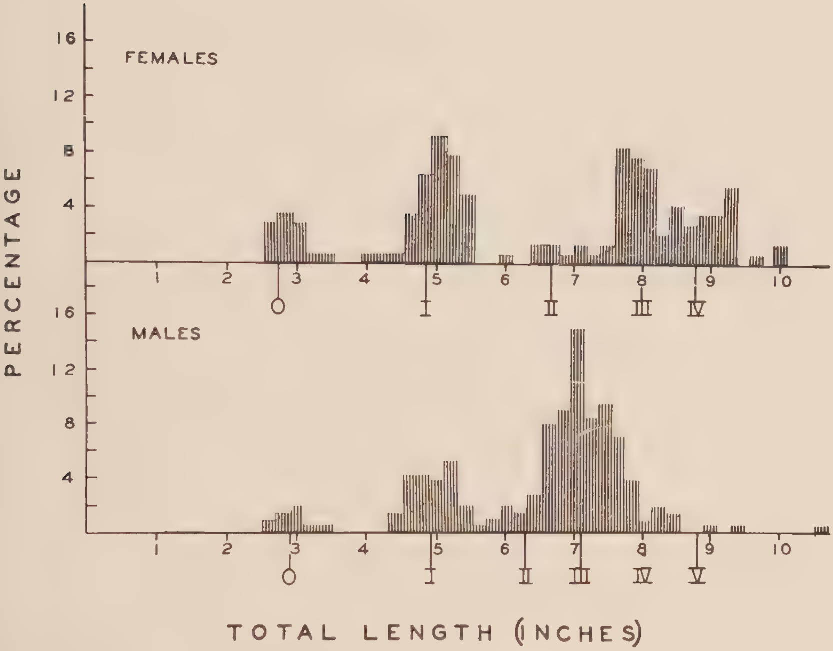

FIGURE 6.—Length distribution of yellow perch taken by trawl off Fayette, Michigan, October 26, 1952. Average lengths of age groups as read from scales are indicated.

As may be seen from Figure 8 (upper curve), the straight line fitted the empirical data reasonably well over the 4.0- to 14.0-inch interval; at fish lengths less than 4.0 inches the lengths of scale radii were consistently greater than the values obtained from the equation. That part of the body-scale curve for fish less than 4 inches long was accordingly fitted by inspection.

The body-scale relation can be employed for the calculation of growth from scale measurements by the use of a formula and a table of corrections. In this procedure the lengths are first calculated from:

$$Ln = 2.0 + \frac{Lt - 2}{St} Sn$$

where Ln = calculated length at end of nth year,
Lt = total length at capture,
Sn = scale radius to nth annulus,
St = scale radius

Calculated lengths of 4.0 inches or greater can be accepted as computed. Calculated lengths less than 4.0 inches are overestimates that can be corrected by the use of Table 7. The corrections in this table, which were determined from the original graph of the body-scale curve, are the vertical distances between the dotted extension of the straight line (Fig. 8 upper curve) and the empirically fitted body-scale curve.

In actual practice the calculations of past growth were made nomographically. First, the body-scale relation was inscribed on a strip of transparent plastic in the manner described by Hile (1950). This strip was then substituted for the ruler in the nomograph devised by Joeris (1950). It was possible with this equipment to record the correct calculated lengths as the scales were measured.

KEY SCALES BELOW THE LATERAL LINE

The original graph of the body-scale data for key scales from below the lateral line indicated that the relation for the larger fish could be described by a straight line passing through or near the origin, but that the relation deviated sharply from this line among the shorter fish. The view concerning the straight-line relation among the longer fish was supported by the values of the body-scale ration L/S which varied randomly (that is, without noticeable trend) at fish lengths greater than 5.4 inches (Table 6; see also Fig. 8, lower curve). For a straight line through the origin, of course, this ratio is constant.

The fitting of a straight line (by least squares) to the body-scale data (mean radii of scales, × 43, for 0.1-inch intervals of total length of fish) yielded the equation:

$$L = 0.127 + 1.522\ S$$

The intercept is so small that for practical purposes it can be ignored.

The body-scale curve for fish less than 5.5 inches long was fitted by inspection.

Calculations of past growth of fish from which scale samples had been removed below the lateral line were made by direct proportion. Calculated lengths of 5.5 inches or longer were recorded as computed, but those smaller than 5.5 inches were underestimates. The corrections that were added to these shorter calculated lengths (Table 7) were determined by measurements of the original body-scale graph. A nomograph was not prepared since the collection of scale samples below the lateral line was abandoned after May 1950.

GROWTH ESTIMATES FROM TWO DIFFERENT BODY-SCALE CURVES

In order that a comparison could be made of the calculated growth of the same fish as determined from each of the body-scale curves, a series of paired scale samples was removed from the Suamico collection of May 27, 1955, one from above and the other from below the lateral line. A comparison of the calculated growth of these fish as determined from the two sets of scales (Table 8) indicates good agreement in all age groups. The maximum discrepancy of 0.10 inch occurred in the second year of life of the VI group. The mean disagreement for all calculated lengths was 0.03 inch (average of absolute values).

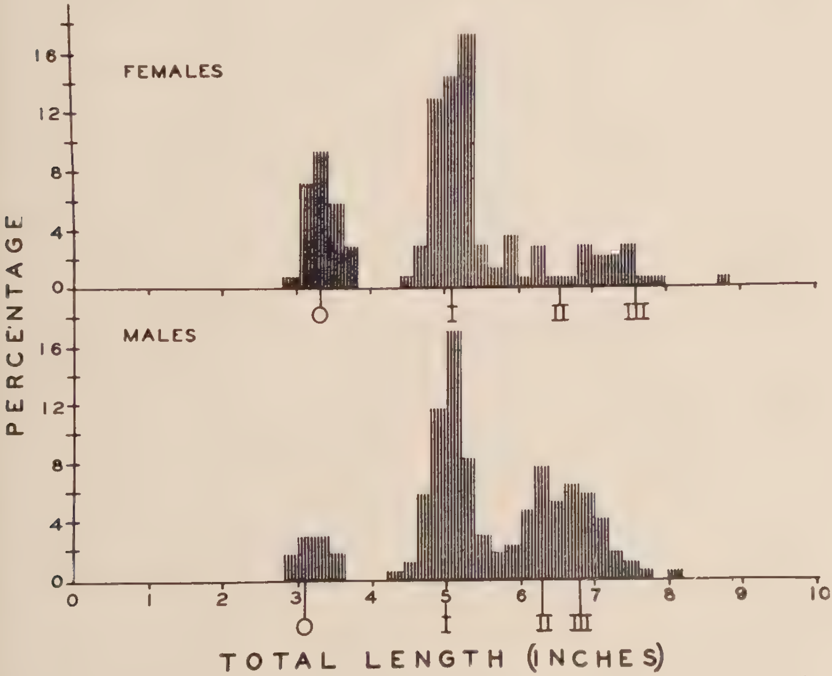

FIGURE 7.—Length distribution of yellow perch taken by trawl off Suamico, Wisconsin, October 22, 1952. Average lengths of age groups as read from scales are indicated.

For individual fish the discrepancy between the calculated lengths from scales above and below the lateral line seldom exceeded 0.2 inch. Th maximum disagreements occurred at the end of the second year of life where an occasional difference of 0.3 or 0.4 inch and one of 0.6 inch occurred.

TABLE 7.—*Corrections (inches) to be added or subtracted from the shorter lengths computed from straight lines to bring them into agreement with the emperically determined body-scale relation of small fish.*

Total length (inches)	Above lateral line	Below lateral line	Total length (inches)	Below lateral line
2.8	—0.30	0.97	4.2	0.76
2.9	—0.29	0.96	4.3	0.74
3.0	—0.28	0.95	4.4	0.70
3.1	—0.25	0.94	4.5	0.65
3.2	—0.22	0.93	4.6	0.61
3.3	—0.19	0.92	4.7	0.57
3.4	—0.16	0.91	4.8	0.51
3.5	—0.14	0.90	4.9	0.44
3.6	—0.10	0.88	5.0	0.36
3.7	—0.07	0.86	5.1	0.30
3.8	—0.04	0.84	5.2	0.24
3.9	—0.01	0.82	5.3	0.17
4.0	..	0.80	5.4	0.08
4.1	..	0.78	5.5	..

TABLE 8.—*Comparison of calculated total lengths (inches) as determined from scales taken above and below the lateral line.*

[Based on the collection of May 27, 1955. Ages were not determined for 2 of the 274 fish in the sample.]

Age group	Scale location	Number of fish	Length at capture	Calculated length at end of year of life					
				1	2	3	4	5	6
II	Above	19	6.63	3.88	6.21	..	..	..	..
	Below			3.93	6.21	..	..	..	..
III	Above	146	7.32	3.65	5.65	7.08	..	..	..
	Below			3.68	5.68	7.08	..	..	..
IV	Above	91	7.56	3.35	5.14	6.40	7.40	..	..
	Below			3.37	5.09	6.36	7.39	..	..
V	Above	9	7.61	3.32	4.80	5.88	6.70	7.53	..
	Below			3.35	4.80	5.88	6.64	7.52	..
VI	Above	7	7.46	3.14	4.63	5.54	6.26	6.77	7.40
	Below			3.21	4.73	5.58	6.19	6.78	7.41

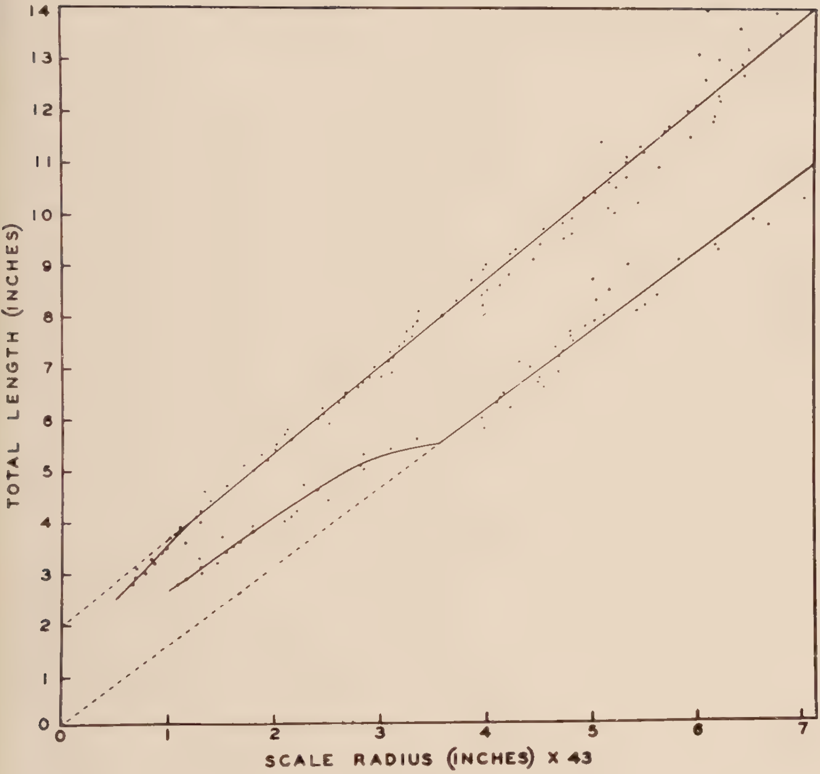

FIGURE 8.—Relation between fish length and the radius of "key" scales above (upper curve) and below the lateral line (lower curve). The dotted portions are extensions of straight lines fitted to data for the larger fish. Dots show the empirical data.

BODY-SCALE RELATION IN THREE GREAT LAKES POPULATIONS OF YELLOW PERCH

The studies that have been made of the body-scale relation for three Great Lakes populations of yellow perch (Lake Erie, Saginaw Bay, Green Bay; all key scales from the same location below the lateral line) agreed on two points: the body-scale ratio was nearly constant among the larger fish; shorter lengths computed by direct proportion were underestimates. The populations differed, however, as to the length range over which direct-proportion calculations were inaccurate and as to the size of the correction needed at a particular length (Table 9). Differences between the Lake Erie and Saginaw Bay stocks were small. Corrections were needed for direct-proportion calculated lengths of Lake Erie fish up to 96 millimeters standard length[5] and in Saginaw Bay up to 102 millimeters. Differences between corrections at corresponding lengths likewise were small. Largest was at 68 millimeters where the correction to be added was 12 millimeters for Lake Erie and 8 millimeters for Saginaw Bay. At other lengths this difference was 1 to 3 millimeters or nil. The use of the body-scale curve from one of these two stocks for computing growth of the other, though not fully justified, would not lead to serious error.

TABLE 9.—*Corrections to be added to direct-proportion calculated standard lengths of three stocks of yellow perch to bring the values into agreement with the empirically determined body-scale relation in small fish.*

[Body-scale relation based on key scales below the lateral line. Data for Lake Erie adapted from Jobes, 1952; those for Saginaw Bay from Hile and Jobes, 1941.]

Direct-proportion calculated length (millimeters)	Correction to be added: Lake Erie	Correction to be added: Saginaw Bay	Correction to be added: Green Bay
36	19	..[1]	..[1]
37-42	18	16	..[1]
43-45	17	15	..[1]
46-49	17	14	..[1]
50-53	16	13	..[1]
54-56	15	12	21
57-58	14	12	21
59-60	14	11	21
61-63	13	10	21
64	13	10	20
65-67	12	9	20
68	12	8	20
69	11	8	20
70-71	10	8	20
72	9	8	19
73-74	9	7	19
75	8	7	19
76-77	8	6	19
78	7	6	19
79	7	6	18
80-83	6	5	18
84	5	4	18
85-86	5	4	17
87	4	4	17
88	3	4	16
89	3	3	16
90-91	2	3	16
92	2	2	16
93	1	2	16
94-95	1	2	15
96-97	..	1	14
98-99	..	1	13
100-101	..	1	12
102-104	..	..	11
105-106	..	..	9
107-108	..	..	8
109-110	..	..	6
111-112	..	..	5
113-114	..	..	4
115-116	..	..	2

[1] Not determined.

The comparison of the data for Saginaw Bay and Green Bay reveals an entirely different situation and discloses the reason for the unsatisfactory results when the growth of yellow perch from Green Bay was computed from the body-scale curve for Saginaw Bay fish. The direct-proportion calculations required correction over a much greater range of length in Green Bay (up to 117 millimeters) than in Saginaw Bay (to 102 millimeters). Furthermore, the values of the corrections at corresponding lengths were consistently greater for the Green Bay fish — often by a wide margin. Over the length range of 54-108 millimeters (direct-proportion) estimates of length of Green Bay perch made from the Saginaw Bay curve are in error by 8 to 14 millimeters. The errors then decline to nil at 117 millimeters.

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[5] Table 9 was prepared in terms of millimeters of standard length because Hile and Jobes (1941) presented their data in that form and Jobes' (1953) corrections in inches had been adapted from a tabulation set up originally in millimeters.

RECOMMENDATIONS ON PROCEDURE

The data on the body-scale relations based on the same key scale in three stocks of yellow perch and on two different key scales from the same stock lead to two important rules of procedure: collectors of scales should be consistent as to the position on the fish's body from which the scales are removed; computations of past growth from scale measurements should not be attempted until the body-scale relation is known for the stock under study.

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BIOLOGICAL INVESTIGATION OF ATLANTIC COAST MENHADEN

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Biological Investigation of Atlantic Coast Menhaden

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INTRODUCTION

THE MENHADENS of North America constitute a resource supporting the largest fishery in the Western Hemisphere. In 1955 landings amounted to over 1.8 billion pounds, or roughly 40 per cent of the total fish production in the United States.

The bulk of the catch is taken by purse seine vessels operating from reduction plants located on the Atlantic and Gulf coasts. A small, but significant, quantity also is taken by pound nets in the middle Atlantic region and in Chesapeake Bay. The catch is processed into fish meal, oil, and condensed solubles.

Four species of menhadens occur throughout the range of the fishery; however, the Atlantic form, *Brevoortia tyrannus,* is by far the most important. It comprises an estimated 75 per cent of the combined annual menhaden production. A second species, *B. smithi,* occurs on the Atlantic coast, but it is of no importance to the fishery at present.

The large-scale commercial fishery for menhaden had its beginning in the late 1850s when the mechanical screw press was adopted for recovering the oil. The fishery subsequently grew rather slowly until about 1870 when the use of steam and the hydraulic press for processing the fish enabled the factory stage to become fully developed. The fishery during this period of expansion was centered in the Gulf of Maine and extended southward along the middle Atlantic coast to southern New Jersey. By 1876 the factories processed approximately 310,000,000 pounds of fish to produce nearly 3,000,000 gallons of oil and over 50,000 tons of fertilizer. In the 1880s the center of menhaden production shifted to the middle Atlantic region following the disappearance of the fish in the waters north of Cape Cod. Subsequently, the fishery expanded southward along the Atlantic coast and into the Gulf of Mexico.

The recent growth of the Atlantic coast fishery is illustrated in Figure 1, showing the landings from 1929 through 1953. It may be seen that the fishery has undergone a marked increase over the 25 year period, with fluctuations clearly evident. The rise in the 1940s was due, in part, to the increased demand for fish meal as an animal feed ingredient. The discovery of vitamin B_{12} as an important constituent of the animal protein factor found in fish meal emphasized the importance of menhaden as a source of this product. Undoubtedly the marked decline of the California sardine and Pacific herring fisheries contributed greatly to the increased demand for menhaden meal.

The menhaden fishery, from its inception, has been subject to great variations in yield. The catch in one region of the coast sometimes differs markedly from those in other regions, or even in adjacent localities in the same season, and periods of high production in a given locality often are followed by several years of poor fishing. Perhaps the most striking example of these vicissitudes was the complete collapse of the fishery in New England in the 1880s. In 1876 seventeen factories located in Maine utilized nearly 142,000,000 pounds of menhaden. Several years later the fish had almost completely disappeared, and except for one or two seasons, they did not return to those waters for nearly 50 years. Since 1950, production in the Gulf of Maine has gradually increased, ar a modern record, based on preliminary data, of over 66,000,000 pounds we produced in 1956.

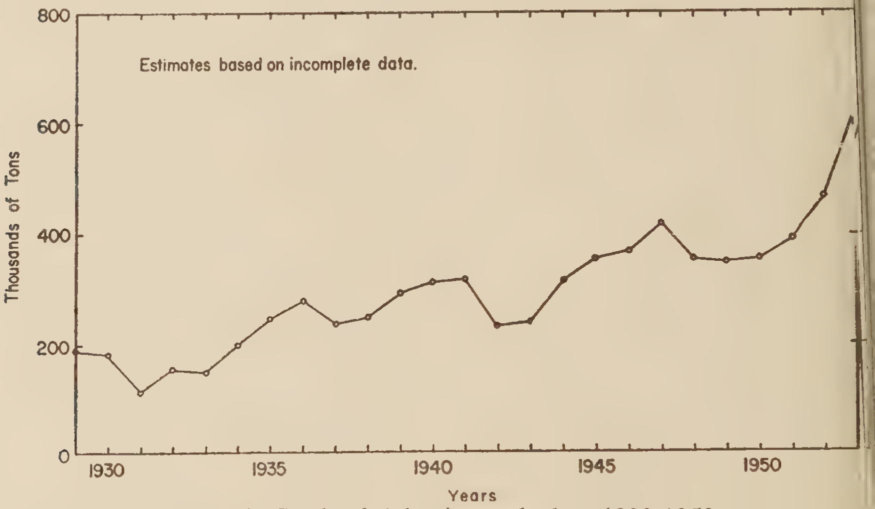

FIGURE 1. Catch of Atlantic menhaden, 1929-1953.

BIOLOGICAL INVESTIGATIONS

An investigation of the menhadens of the Atlantic coast was undertaken early in 1955 by the U. S. Fish and Wildlife Service. The program is an expansion of preliminary biological studies initiated in 1952. The program of investigation is designed to determine the causes of fluctuations in the fishery and the extent to which these are predictable. Since *Brevoortia tyrannus* at present is the only important species in the commercial fishery in the Atlantic, research activities, for the most part, have been limited to this species. The immediate objectives of the work are to (1) determine the structure and relationships of populations, (2) gather knowledge respecting its life history and biology, and (3) follow changes in the age and size composition of the stock in relation to fluctuations in the catch. In addition, measurements of catch, fishing effort, and abundance are being compiled from records of landings at the reduction plants and fishing logbooks kept by the fishermen.

DISTRIBUTION

The present distribution of the Atlantic menhaden *(B. tyrannus)* is known to include the area roughly from Boothbay Harbor, Maine, southward to Daytona Beach, Florida, and offshore to a distance of less than 75 miles. It is not found in equal abundance throughout this range, but is concentrated in localities where feeding conditions appear to be most favorable. It is found in greatest numbers during the warmer months of the year when the fish congregate at the surface in schools of many thousands and even millions of individuals.

The commercial fishery covers the presently known range of this species. In Figure 2 is shown the geographical distribution of purse seine fishing, with the areas of heaviest concentration shaded more heavily. The data on which the

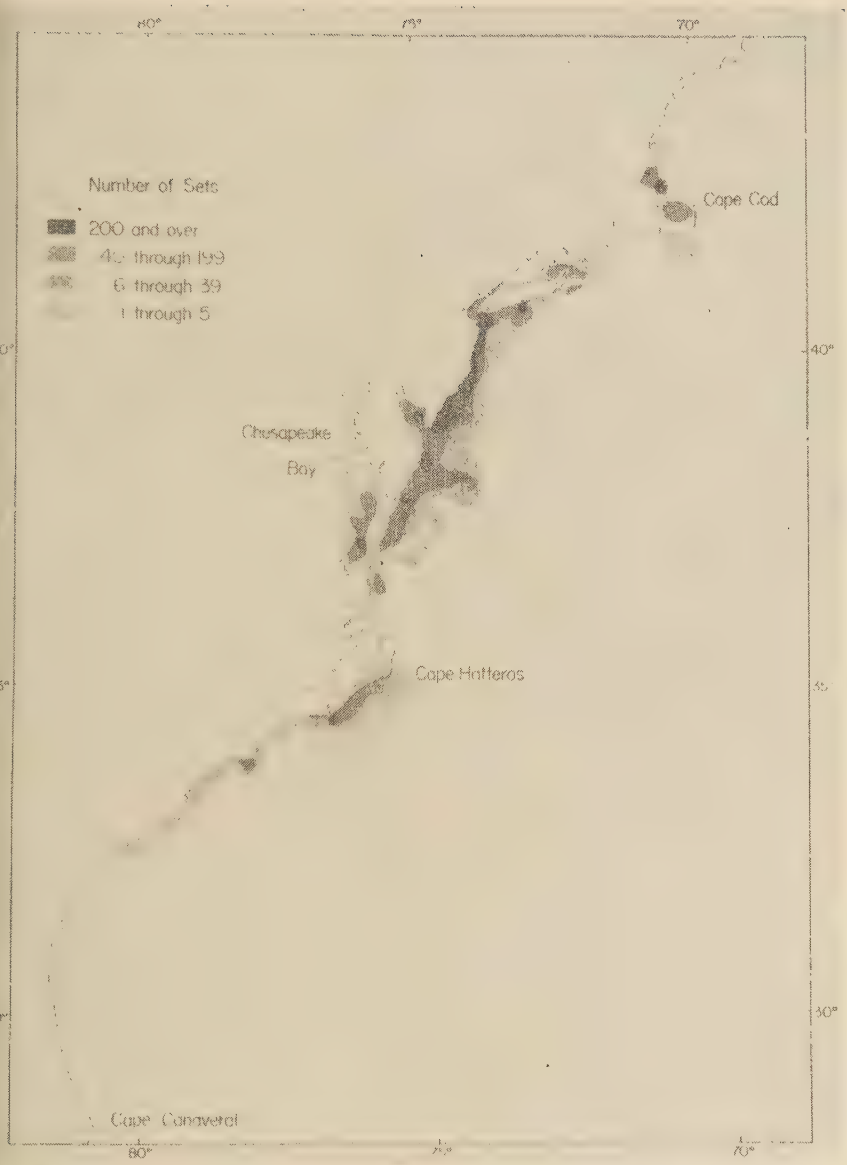

FIGURE 2. Geographical distribution of purse seine fishing, 1955.

figure is based are taken from fishing logbook records kept by vessel captains and pilots.

POPULATIONS

Since the Atlantic menhaden occupies some 3,000 miles of coastline, it is necessary first of all to determine whether it exists as a single, freely intermingling and interbreeding group of fish, or whether there are several independent or semi-independent groups, each with its own biological peculiarities.

From several lines of evidence we have concluded tentatively that there exists at least two distinct populations. Comparisons of average numbers of vertebrae, fin rays, and ventral scutes of juvenile menhaden reveal rather large differences between those fish inhabiting estuarine nursery areas north of Long Island and those occurring south of Long Island. Furthermore, size frequency distributions indicate that juveniles occurring in those estuaries north of Long Island reasonably could not have arisen from the same spawning as those from farther southward. Those from northern waters are considerably smaller than those in estuaries south of Long Island.

It is known that a major spawning occurs off the coast of the Carolinas during the fall and winter months. There also is evidence to indicate that a separate spawning, presumably by a different group of fish, occurs in waters north of Long Island in the spring and early summer under very different environmental conditions. Thus, it is hypothesized that adult fish segregate into at least two distinct groups for spawning, and the observed differences in body structure of juveniles are induced either by inherited tendencies which are preserved, or differences in environmental conditions at the time of spawning, or they may result from the interaction of both influences.

Persistent differences in size of menhaden of the same age also occur. Two and three year old fish, for example, are larger in the northern limit of the geographical range of a year class; smaller fish occur farther south, while those intermediate in size are found in the central region. These differences are believed to represent differences in growth rates arising from different populations.

We also are studying body structure of spawning fish from both the northern and southern areas to determine whether they differ and the extent to which they resemble juveniles from adjacent nursery areas. However, progress on this work has been too limited to permit any conclusions at this time.

LIFE HISTORY AND BIOLOGY

Knowledge of the basic features in the life history and biology of menhaden and their relation to the physical and biological environment is essential to understanding changes within populations and their effects on the fishery. If the events in the life history of each year class could be followed closely from the time of its origin as eggs on the spawning grounds, it is likely that the reasons underlying its success or failure could be adduced. Certain stages in the early life history, for example, may be found to be especially critical, explaining why variations in year class survival occur. Thus, determination of the causes of variation in mortality rates of eggs and young would aid in predicting the abundance of year classes.

To provide a frame of reference for the execution of an investigation of this type, we have begun with the earliest stage in the life history, i.e. spawning. Detailed studies are being made of the gonads of fish sampled from the pound net and purse seine fisheries throughout the year to determine the times and places of spawning and the size and age at which sexual maturity is attained. In addition, limited plankton work, both at sea and in estuaries, is being conducted to determine the distribution of eggs and larvae in time and space.

Results thus far obtained indicate that spawning occurs over a wide geographical range and during the entire year. Spawning appears to be largely concentrated in the fall and winter months off the coast of the Carolinas. This spawning appears to have its beginning in the vicinity of Long Island, and possibly farther northward, in the fall when a southward movement of the fish is in progress. Based on extensive sampling of the catches over the past three years, all fish present in those waters at the close of the fishing season in October have been found to be sexually mature; however, roughly only 60 per cent are in spawning condition. The remainder, comprising fish of the same size and age, are in non-spawning condition. Several weeks later identical size and age groups of fish occur in the fishery off the North Carolina coast, but only fish in spawning condition have been found in our samples to date. These findings suggest that although fish in varying stages of sexual development occur together in northern waters in late summer and early fall, spawning fish somehow become segregated from non-spawning individuals between the time of the disappearance of the former group from Long Island waters after the close of the purse seine fishing season and the appearance of spawning fish in North Carolina waters a short time later. Indeed, fish in non-spawning condition, representing the same size and age groups, have been taken in large numbers by the pound net and mackerel gill net fisheries along the New Jersey coast at the same time that spawning fish make their appearance in North Carolina waters.

It also appears that a later spawning takes place in waters north of Long Island in spring and early summer. Fish with gonads in developing stages of ripeness enter the pound net fisheries in the vicinity of Raritan Bay and central Long Island normally in March and April. Within a period of several weeks, these fish disappear from the fisheries, and a short time later, identical size groups, with many individuals in partially spawned-out condition and others in advancing stages of ripeness, make their appearance in the pound net catches in the vicinity of Block Island. Nowhere else along the coast are fish in spawning condition encountered at that time of year.

We presently are developing a method, based on ova diameters and ovary weight, of determining rapidly and objectively the stages of maturity of the gonads to provide more efficient and extensive information concerning these phenomena.

Present knowledge indicates that spawning and early larval development take place entirely in the ocean and possibly are limited to the waters over the continental shelf. Some time after absorption of the yolk sac, the larvae enter estuaries and bays and spend the following several months of their life in these nursery areas. In the fall the juveniles emigrate from the estuaries and apparently migrate southward, for they occur in tremendous numbers along the coast of North Carolina in late fall, and frequently large schools may be seen along the shore in northern waters traveling in a southward direction. Furthermore, during the following summer these fish appear as one year-olds only in the southern and central parts of the range. Such a distribution would be possible only if juveniles migrated into those waters sometime after they left the estuaries.

Investigation of the biology of larval menhaden also is being conducted under controlled conditions in the laboratory. Preliminary studies of their feeding habits, using radioactive tracer elements, suggest that, following absorption of the yolk sac, they feed mostly on copepods, a small crustacean. A change in feeding habits is believed to occur when the gill rakers (a straining apparatus) become developed. At this later stage their food consists predominantly of microscopic plants and animals, including diatoms and flagellates. Other experimental studies are concerned with rearing larvae under different conditions of temperature and salinity to determine the effects of these factors on growth and morphology.

An intensive study of the estuarine life of juvenile menhaden also is being carried on at our field laboratory located at Indian River, Delaware to determine (1) mortality rate, (2) growth, (3) amount of intermingling of juveniles within the estuary, (4) feeding habits and food preferences, and (5) responses of populations to changes in physical and biological features of the environment.

Results of this work indicate that juveniles do not occur randomly in the nursery areas, but tend to be congregated where phytoplankton production is highest. Growth under these conditions is rapid, for by the time that they are ready to emigrate from the estuaries in the fall, young fish have attained a maximum length of about six inches. Varying conditions of salinity, temperature, and oxygen also influence the distribution and behavior of juveniles in the estuaries. The most difficult problem concerned with the estuarine phase of the program is to devise suitable measures of mortality rate and abundance. The findings to date respecting these two features are inconclusive, but some have been noted which will form a basis for future work.

Following their early life in the estuaries, menhaden appear to be restricted to the littoral, or coastal, waters to roughly the 20-fathom curve. One of the most outstanding characteristics of the fish is its tendency to aggregate into dense schools near the surface. A further feature, significant to the study of its biology, is the tendency of individuals of the same size to school together. So far as we know, juveniles, following their emigration from estuarine nursery grounds, always school separately. One year old fish usually do, but the largest may join schools of smaller two year old fish. Furthermore, differences in the size distribution of samples from schools in a given area indicate a tendency for schools of a given size range to occur together distinct from those of an adjacent, but overlapping area.

Sampling of the catches to obtain estimates of various parameters of the population, therefore, involves drawing samples from a large number of different schools over the range of the fishery during given time periods. The main purpose underlying this phase of the investigation is to study variations in the strength of successive year broods, or year classes, of fish and their effect on the catch. These data also will furnish information on growth, migrations, mortality rates, and the population structure of the stock. In addition, information is being obtained on other pertinent biological features, including length and weight of fish at each age, sex ratio, and spawning.

Our present sampling program consists of obtaining representative samples of the catches at each location along the Atlantic coast where pound net and purse seine fisheries are active. The number of samples taken is roughly proportional to the catch in each locality.

The results of this work over the past two years reveal several outstanding features. Most important of these, perhaps, deals with the distribution of size and age groups in the fishery. During the summer months the older, sexually mature fish occur only in northern waters, while the younger, sexually immature fish occur only in the southern and central parts of the range. The data further indicate that one year old fish gradually move northward during the summer, and by late summer, most of the one year old fish have disappeared from southern waters. In each succeeding year this northward movement of a year class becomes more pronounced. Thus, a gradual mixing of size and age groups takes place. A southward migration occurs in the fall and early winter when those size and age groups occurring in the summer fishery north of Cape Hatteras appear in the fall and winter fishery off the coast of North Carolina. There appear to be slight variations in this generalized pattern of distribution from year to year. One year old fish, for example, may occur as far northward as New Jersey in some years, while in other years, they may reach no farther northward than Virginia. Furthermore, during mild winters, one and two year old, sexually immature fish apparently do not all move southward, for great numbers are taken in the pound net and gill net fisheries off the Maryland and New Jersey coasts.

Another significant finding is that marked variation in year class strength is evident. Although not completely documented, the 1951 year class, for example, predominated in the catch for several years and still is contributing an important share of the landings. The 1952 year class, on the other hand, appears to have been a rather poor one and has contributed relatively little to the fishery. A great deal remains to be learned, but sufficient data are being accumulated to assess this feature of the fishery.

MEASUREMENTS OF CATCH

Measurements of the abundance, amount of fishing effort, and total catch of menhaden are essential for evaluating and interpreting fluctuations in the fishery. These statistics require detailed data over a series of years regarding the time, place and amount of the catches, together with information on the amount of fishing effort that is required to take them. Such information is being obtained from the records of individual vessel landings kept by the processing plants and from fishing logbooks kept by the fishing fleet.

Measurements of total catch, apparent abundance, and total fishing effort have been completed for the middle Atlantic area from 1939 through 1954. A second measurement of apparent abundance is being calculated based on the logbook data. The two series of measurements will be compared to determine if they indicate the same conclusions.

Compilation and analyses of these basic data have been partially completed for the south Atlantic and Chesapeake Bay areas. Progress on this phase of the program has been slow because of the great bulk of material; however, we hope to complete the analysis of the historical data during the coming fiscal year.

OBSERVATIONS ON SEA BIRDS IN THE TROPICAL PACIFIC

By JOSEPH E. KING and ROBERT L. PYLE

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OBSERVATIONS ON SEA BIRDS IN THE TROPICAL PACIFIC

By JOSEPH E. KING and ROBERT L. PYLE

The Pacific Oceanic Fishery Investigations (POFI) of the United States Fish and Wildlife Service, with headquarters in Honolulu, is engaged in a program of oceanographic and fisheries research in the central Pacific. In the period from September 23 to December 17, 1955, the POFI vessel *Hugh M. Smith* made an 86-day, 13,800-mile cruise which afforded the authors an unusual opportunity to observe the sea birds in the equatorial region of the eastern and central Pacific, an area which is not frequently visited by ornithologists.

This cruise of the *Smith*, forming a part of the "Eastropic" expedition in which several research agencies collaborated, followed the route shown in figure 1. The primary objective of the cruise was to obtain information on east-west gradients in water temperature, salinity, chemical nutrients, and abundance of plankton and forage organisms in relation to the current system.

It is standard procedure on POFI cruises for the crewmen standing wheelwatch to record all bird flocks and scattered birds sighted each day. These observations are not usually to the species level, however. In addition to this watch by the crewmen, King maintained throughout the cruise a 1-hour watch each day between 4 and 5 p.m., during which period an effort was made to count and identify to species all birds sighted. On the westbound leg of the cruise, a similar watch was performed each morning, usually at 6 to 7 a.m., by Pyle, who joined the expedition at Manzanillo. The results of these observations, with particular emphasis on the variations in abundance and distribution of the sea birds in respect to the equatorial current system, and an annotated list of the species sighted, are the subject of this report.

In our record keeping we tried to distinguish between scattered birds and birds in flocks. Five or more birds traveling or feeding together as an aggregate were considered a flock. The number of flocks sighted each day and the number (frequently estimated) of individuals in each flock are given in table 1. It is evident from the table that bird flocks varying greatly in number of individuals were observed on less than half the days of the cruise, whereas scattered birds were sighted every day. Because of the small number of bird flocks and their distorting effect on the daily averages, they have been omitted from the detailed analysis in the sections to follow. The average number of scattered birds seen per hour for each day (table 1, fig. 1) was obtained by combining the number sighted by the wheelwatch in 9 to 12 hours of observation with the number sighted by Pyle in one hour and the number sighted by King in one hour, then dividing by the total hours put in each day. We recognize that the "average number" calculated in this manner is hardly an ideal statistic, but it does provide an index to the day-to-day variation in bird abundance and it seemed to be the best way to combine and utilize the available data. All observations made within one day's running (approximately 200 miles) of the Mexican coast or of the different island groups were omitted from the calculations although the species were recorded. Close to land the numbers of birds increased so markedly that an accurate count was impossible.

The identifications are based almost entirely on careful sight records, although representatives of several species came aboard the vessel and were examined in the hand. These included: Wedge-tailed Shearwater, Christmas Shearwater, Black-vented Shearwater, Tahiti Petrel, Hawaiian Petrel, White-throated Storm-petrel, Madeiran Storm-petrel, Leach Storm-petrel, and Sooty Tern. The crewmen were all skilled fishermen who were well acquainted with the common species and possessed remarkable ability to sight birds at considerable distances. There was doubtless some individual variation in the

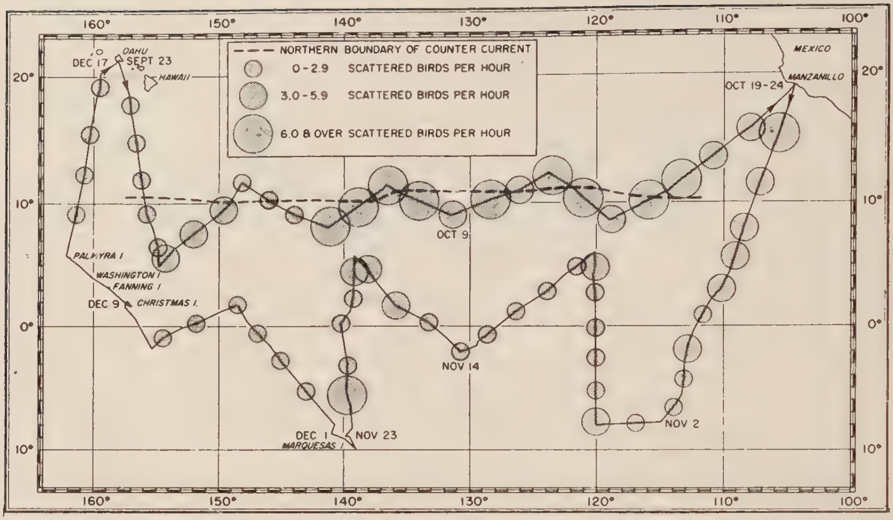

Fig. 1. Track of the M/V *Hugh M. Smith* on the "Eastropic" cruise showing variations in number of scattered birds seen per hour for each day of observation. Sightings by King, Pyle, and the wheelwatch were combined and the resulting average figures grouped into three classes: 0 to 2.9, 3.0 to 5.9, and 6.0 birds and over. The value for each day is plotted at the noon position. All observations within one day's run (about 200 miles) of land were omitted.

Table 1

Average Numbers of Scattered Birds and Birds in Flocks Sighted Each Day of the "Eastropic" Cruise of the *Hugh H. Smith,* Omitting All Observations within One Day's Run (about 200 Miles) of Land

			Scattered birds				Birds in flocks	
Date 1955	Noon position Latitude	Longitude	Morning watch, 1 hr.[1]	Afternoon watch, 1 hr.[2]	Wheel-watch, av. No./hr.[3]	Total, av. No./hr.[4]	No. of flocks/ day[4]	No. of birds in flocks
9/24	17°49′N	157°09′W	....	....	1.0	1.0	0	....
9/25	15°56′N	156°37′W	....	7	1.0	1.5	0	....
9/26	11°56′N	156°12′W	....	....	2.4	2.4	6	309
9/27	09°10′N	155°47′W	....	1	1.5	1.5	0	....
9/28	06°33′N	154°48′W	....	....	1.8	1.8	0	....
9/29	05°31′N	154°13′W	....	10	2.8	3.4	1	25
9/30	07°28′N	151°58′W	....	11	3.5	4.1	5	206
10/1	09°24′N	149°34′W	....	11	4.8	5.4	0	....
10/2	11°38′N	148°04′W	....	5	0.8	1.2	0	....
10/3	10°15′N	145°57′W	....	5	1.0	1.4	0	....
10/4	09°04′N	143°49′W	....	5	2.1	2.4	0	....
10/5	08°00′N	141°10′W	....	4	6.7	6.4	0	....
10/6	09°43′N	138°51′W	....	29	6.3	8.4	3	80
10/7	11°14′N	136°30′W	....	12	5.9	6.5	0	....
10/8	10°09′N	133°59′W	....	15	6.3	7.1	3	175
10/9	09°01′N	131°21′W	....	18	2.3	3.7	2	62
10/10	10°12′N	128°13′W	....	6	7.8	7.4	2	50
10/11	11°00′N	126°02′W	....	9	3.4	3.9	1	50
10/12	12°08′N	123°34′W	....	9	7.7	7.7	1	30
10/13	10°18′N	121°04′W	....	12	7.1	7.5	2	65
10/14	08°36′N	118°50′W	....	6	3.9	4.1	0	....
10/15	10°05′N	115°51′W	....	14	6.9	7.5	1	30
10/16	11°40′N	113°25′W	....	19	10.0	10.5	1	8
10/17	13°36′N	110°51′W	....	6	3.2	3.4	1	20

Date 1955	Noon position Latitude	Noon position Longitude	Scattered birds: Morning watch, 1 hr.[1]	Scattered birds: Afternoon watch, 1 hr.[2]	Scattered birds: Wheel-watch, av. No./hr.[3]	Total, av. No./hr.[4]	Birds in flocks: No. of flocks/day[4]	Birds in flocks: No. of birds in flocks
10/18	15°46′N	107°57′W	....	2	4.2	3.0	1	35
10/19–24	Mexico							
10/25	15°16′N	105°44′W	4	33	7.0	8.6	1	150
10/26	11°33′N	107°08′W	8	20	4.1	5.2	3	18
10/27	07°58′N	108°25′W	14	8	6.0	5.9	0	....
10/28	05°41′N	109°06′W	19	4	4.3	5.6	0	....
10/29	03°04′N	110°10′W	4	4	3.3	3.4	1	45
10/30	00°59′N	111°32′W	0	4	1.2	1.4	0	....
10/31	01°40′S	112°52′W	15	0	4.0	4.6	0	....
11/1	04°25′S	112°50′W	....	5	1.6	2.0	0	....
11/2	06°46′S	113°54′W	1	0	1.8	1.6	0	....
11/3	07°53′S	116°50′W	0	4	1.1	1.4	0	....
11/4	07°46′S	120°00′W	7	16	2.9	4.5	2	30
11/5	05°14′S	120°00′W	3	3	1.3	1.6	0	....
11/6	02°38′S	120°01′W	1	1	1.8	1.6	1	25
11/7	00°03′S	119°52′W	1	0	2.1	1.8	0	....
11/8	02°50′N	120°00′W	1	10	1.0	1.8	1	17
11/9	04°55′N	120°05′W	18	10	2.0	4.2	0	....
11/10	04°56′N	121°26′W	0	0	1.3	1.1	0	....
11/11	02°52′N	123°50′W	0	6	1.8	2.0	0	....
11/12	01°11′N	126°23′W	0	0	0.6	0.5	0	....
11/13	00°32′S	128°40′W	4	6	2.1	2.6	1	5
11/14	02°02′S	130°46′W	3	4	1.2	1.6	0	....
11/15	00°14′N	133°12′W	0	0	1.0	0.8	0	....
11/16	01°44′N	135°50′W	4	4	4.9	4.7	0	....
11/17	04°48′N	138°16′W	2	3	3.6	3.4	0	....
11/18	04°26′N	139°09′W	0	8	6.1	5.7	1	50
11/19	02°13′N	139°11′W	0	6	1.2	1.5	0	....
11/20	00°14′N	140°10′W	2	2	0.6	0.8	0	....
11/21	03°02′S	139°44′W	1	0	1.0	0.9	0	....
11/22	05°36′S	139°50′W	1	4	8.4	7.4	1	16
11/23–12/1	Marquesas Islands							
12/2	05°13′S	143°01′W	4	2	1.0	1.3	3	113
12/3	02°40′S	145°04′W	2	3	0.7	1.0	0	....
12/4	00°27′S	146°54′W	2	0	0.3	0.4	0	....
12/5	01°42′N	148°38′W	2	1	0.9	1.0	1	25
12/6	00°17′N	151°45′W	4	1	1.3	1.5	1	80
12/7	00°51′S	154°30′W	2	1	1.2	1.2	0	....
12/8–12	Line Islands							
12/13	09°02′N	161°23′W	1	1	0.5	0.5	0	....
12/14	12°18′N	160°43′W	0	1	0.5	0.5	0	....
12/15	15°38′N	160°13′W	2	0	0.4	0.4	0	....
12/16	19°12′N	159°23′W	1	0	0.1	0.1	0	....

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[1] By R. Pyle, usually at 6:00 to 7:00 a.m.
[2] By J. King, usually at 4:00 to 5:00 p.m.
[3] With observations throughout a 9- to 12-hour day.
[4] Includes sightings by the wheel-watch, R. Pyle and J. King.

effort they expended and in their interest in the project, but the watch was rotated each day so that differences among observers probably did not greatly influence the results. The bulk of the time spent on these observations was contributed by the crewmen, and we wish to acknowledge and thank them for their assistance.

The most important sources of error in our records, we believe, are those related to the difficulties of accurately observing and identifying birds from a small vessel on the open sea. Many of the birds do not follow the ship but remain at a distance; they are usually seen in fast flight and rarely resting on the surface; the vessel is always rolling and pitching to some degree, making it difficult to hold binoculars steady; and individuals of some species that have the habit of following vessels may have been counted more than once. Our observations were made from the upper deck of the vessel where visibility was excellent and a bird in flight could be followed through 360° if desired. Also, weather conditions were generally good throughout the cruise; on only a few days did heavy rain or rough seas interfere to any extent. Our data provide some measure of the variation in bird sightings in relation to sea surface and amount of cloud cover.

The most widely used reference in making identifications was Alexander (1954). In the eastern Pacific the publications of Murphy (1936), Peterson (1941), and Blake (1953) were also helpful.

Previous records, principally on the occurrence and distribution of sea birds in the central Pacific, have been provided by Murphy (1924, 1928, 1929), Jespersen (1932–33), Fleming (1950), and Macdonald and Lawford (1954). The nearest approach to an analysis of the bird populations and their relation to environmental factors is that of Murphy and Ikehara (1955) for the mid-central Pacific. No quantitative studies as comprehensive as those of Jespersen (1930) and Moore (1951) on sea birds of the North Atlantic, have been made in the Pacific, to our knowledge. The present study does not change this situation to any great degree but does provide some information on variations in the numbers of birds as related to the current system and to certain other features of the environment.

DESCRIPTION OF THE ENVIRONMENT

The general pattern of the Pacific equatorial current system has been described by Sverdrup, Johnson, and Fleming (1942:708–712). In brief, the major surface currents of this region are the North and South Equatorial Currents flowing toward the west, and the eastward-flowing Equatorial Countercurrent lying in between. Although the boundaries of the Countercurrent (CC) may vary meridionally with longitude and season, its southern and northern boundaries ordinarily occur near 5°N and 10°N latitude in the eastern central Pacific. The South Equatorial Current (SEC) is therefore on both sides of the Equator while the North Equatorial Current (NEC) is confined entirely to the Northern Hemisphere. The general features outlined here apply principally to the central Pacific and may not hold for the extreme eastern part of the region. A detailed study of the oceanographic data from this area is presently being made by POFI and other research agencies.

The Equator is the site of upwelling resulting from divergence of the surface waters. The newly upwelled water is high in nutrients and provides a favorable environment for the growth of plankton. Convergence and sinking of the surface waters, occurring between about 2°N latitude and the southern boundary of the CC, may tend to concentrate the plankton into a rich pasturage for forage organisms, which in turn serve as food for the larger fishes such as the tunas and also for the sea birds.

Enrichment of the surface water by an entirely different mechanism is thought to occur along the northern boundary of the CC. In the eastern and central Pacific this boundary region is an area of shallow thermocline with high-phosphate water occurring within the photosynthetic zone and within the reach of wind-induced turbulence. To the westward the thermocline deepens, reducing the likelihood of enrichment of the surface layer through this combination of factors.

VARIATIONS

Current system.—For purposes of examining variations in bird abundance as related to the current system, we use the six latitudinal subdivisions of the area established by

King and Hida (MS). These are based on natural features and are defined as follows: (1) the NEC from about 20°N latitude to the northern boundary of the CC; (2) the CC with its boundaries being determined at the time of each crossing from vertical temperature sections; (3) a zone of convergence in the SEC extending from the southern boundary of the CC to 1½°N latitude; (4) a zone of divergence and upwelling in the SEC along the Equator from 1½°N to 1½°S latitude; (5) the SEC from 1½°S to 5°S latitude; and (6) the SEC from 5°S to about 14°S latitude. Since special effort was spent on our cruise to investigate the northern boundary of the CC, we established a seventh subdivision of 2 degrees of latitude extending from 1 degree north of the current boundary to 1 degree south of the boundary. The latitudinal limits of these seven zones are shown in figure 2.

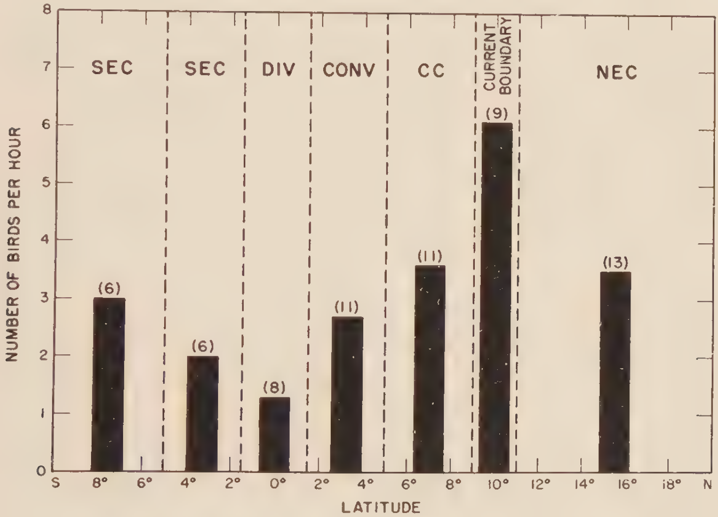

Fig. 2. Variation in numbers of scattered birds sighted per hour of observation in relation to the current system. All sightings within one day's run (about 200 miles) of land were omitted. Number of days on which each average value is based is shown in parentheses.

When the numbers of scattered birds are combined in accordance with these subdivisions of the current system, omitting all sightings within one day's run of land and disregarding differences associated with longitude, we find the largest number of birds occurring along the northern boundary of the Countercurrent and the least number in the zone of divergence on the Equator (fig. 2). It is evident from table 1 that the number of bird flocks was also greater in the region of the Countercurrent than near the Equator; for example on the eastbound leg, 30 bird flocks including a total of about 1145 birds were seen on 25 days (1.2 flocks or 38 birds per day) whereas on the westbound leg south of the CC (south of 5°N) only 13 flocks including about 406 birds were seen on 31 days (0.4 flocks or 13 birds per day). This distribution is generally similar to that described by Murphy and Ikehara (1955, fig. 7) for the central Pacific and also closely parallels the abundance of bigeye tuna (*Parathunnus sibi*) as determined from POFI longline fishing, but is inversely correlated (King and Hida, MS) with the catch of yellowfin tuna (*Neothunnus macropterus*). Reasons for these apparent relationships between birds and subsurface fish are obscure and will not be discussed further in this paper.

In the eastern Pacific (120°W–140°W longitude) the distribution of zooplankton shows a double peak, being high both at the Equator and at the northern boundary of the CC (King and Hida, MS). Of these two "enriched" areas the sea birds, as well as the bigeye tuna, seem to find better foraging conditions at the northern boundary of the CC.

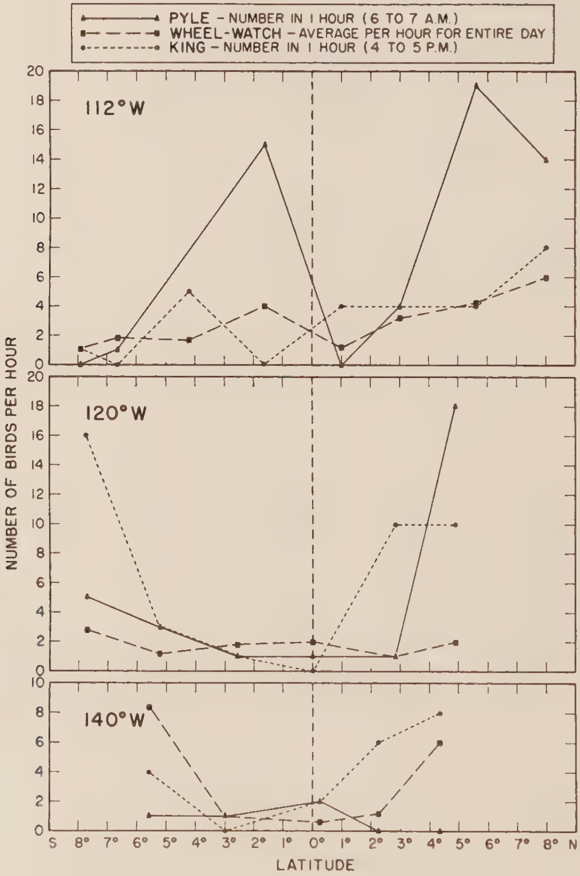

Fig. 3. Variation in numbers of scattered birds comparing the sightings of Pyle, King, and the wheelwatch on three north-south section lines crossing the Equator on longitude 112°, 120°, and 140°W, with the values for each day's observations plotted on the noon position. All sightings within one day's run (about 200 miles) of land were omitted.

Figure 3 shows the latitudinal distribution of scattered birds on the three long station lines crossing the Equator on 112°, 120°, and 140°W longitude. Despite the considerable variation among observers there is evidence of reduced numbers on the Equator and increases to the north and south.

Longitude.—When numbers of scattered birds are combined by 10-degree intervals of longitude, disregarding differences associated with latitude, we obtain a picture (fig. 4) of generally increasing abundance from west to east, with peaks at 140°W and at 110°W longitude. This distribution is probably influenced by the occurrence of the Marquesas

Islands at about 10°S latitude, 140°W longitude and the nearness of the Mexican coast on the east, even though observations within one day's run of land were omitted. The generally low abundance west of 140°W longitude and the increase in numbers along the northern boundary of the CC east of 140°W longitude are clearly shown in figure 1.

There was apparently little variation from east to west in number of bird flocks. The highest average number of flocks (1.1) and the largest average number of birds in flocks (43) sighted per day was recorded for 130°W longitude.

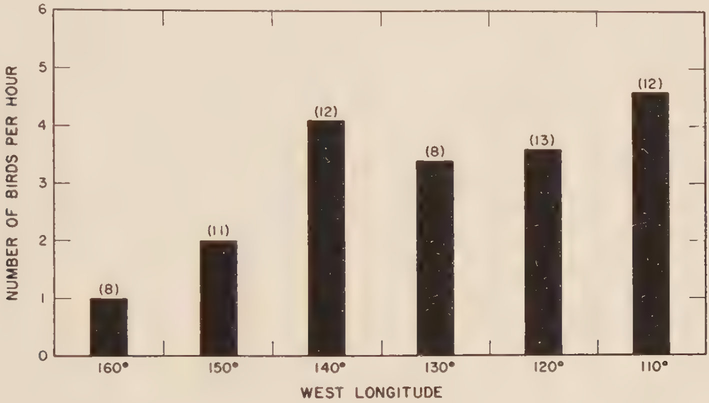

Fig. 4. East-west variation in numbers of scattered birds by 10-degree intervals of longitude. Number of days on which each average value is based is shown in parentheses.

Diurnal.—Our data provide some indication that, during daylight hours, scattered birds were most numerous in the late afternoon period. Numbers of scattered birds sighted by the wheelwatch for each hour from dawn to dusk (6 a.m. to 7 p.m.), and averaged for the entire cruise, but omitting all observations within one day's run of land areas, are shown in figure 5. As the plankton work was conducted each day between 9 and 11 a.m., the bird observations during this period were few and probably not of

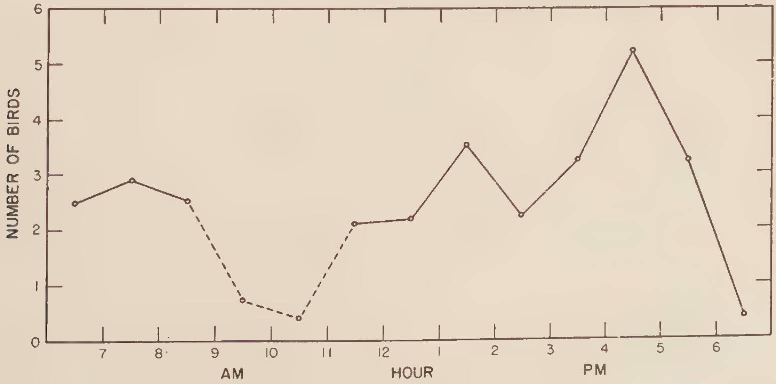

Fig. 5. Variation in number of scattered birds from dawn to dusk as sighted by the wheelwatch. Sightings during 9 and 10 a.m. hours are probably not quantitative. All observations within one day's run (about 200 miles) of land were omitted.

quantitative nature. The peak between 4 and 5 p.m. seems significant although it is partly explained by the presence on the bridge of two observers who were of some assistance to each other in locating birds.

Further evidence of a slightly greater number of scattered birds in flight in the late afternoon, as compared with the early morning, is given by the average sightings of the two special observers on the westbound leg. In the afternoon watch King sighted an average of 4.5 birds per hour whereas in the morning watch Pyle sighted an average of 3.5 per hour. The number of bird flocks varied irregularly with the hour of day, but 36 flocks were sighted between 12 noon and 6 p.m. as compared with 11 flocks between 6 a.m. and 12 noon.

Miscellaneous.—Two factors which may affect the observer's ability to see birds at sea are amount of overcast or cloud cover and the nature of the sea surface. On a clear, calm day bird flocks can be seen with fair regularity at two to three miles with the unaided eye and single birds at one to two miles. With reduction in light through cloudiness and with higher waves and swell to hide low-flying birds it is reasonable to suppose that fewer birds will be seen than under ideal conditions, assuming their actual numbers remain the same.

Although our data are perhaps not sufficient to provide definite conclusions, it would appear from table 2 that increasing cloudiness had no effect on the numbers of scattered birds sighted. Table 3 indicates, on the other hand, that increasing wave height resulted in fewer birds seen. We have no way of knowing, of course, if the true abundance of birds in flight changed with changes in sea surface.

Table 2

Variation in Number of Scattered Birds Sighted in Relation to Amount of Cloud Cover[1]

	Cloud cover, in eighths		
	0–2	3–5	6–8
Average number of birds/hour	5.4	4.3	5.9
Number of hours observed	38	18	46

[1] Based on observations by R. Pyle and J. King during early morning and late afternoon watches.

It is believed that sharp temperature discontinuities or "fronts" occurring in the ocean surface layer may have a concentrating effect on plankton, the basic food in the sea, and consequently influence the distribution of other marine animals. On the westbound leg of our cruise the ship's thermograph (not operating on the eastbound leg of the cruise) recorded 17 fronts with temperature differences across the front ranging from ½° to 4°F. When the positions of these sharp temperature breaks were plotted on a chart similar to figure 1, together with numbers of scattered birds and bird flocks, we could see no evidence of a causal relationship. In only four instances were bird flocks sighted either working over a front or within an hour's run of the temperature discontinuity. We conclude, therefore, that on this cruise the phenomenon had little or no influence on bird distribution or overall bird abundance.

Table 3

Variation in Number of Scattered Birds Sighted in Relation to Sea Surface[1]

	Sea surface, height of waves, in feet			
	< 1	1–3	3–5	5–8
Average number of birds/hour	9.3	6.4	5.0	3.1
Number of hours observed	3	36	55	8

[1] Based on observations by R. Pyle and J. King during early morning and late afternoon watches.

ANNOTATED LIST OF SPECIES

The following species of birds were recorded at sea during the cruise. In many instances records are given by date: the approximate coordinates of these observations may be determined from figure 1 and table 1. Peters (1931, 1934) has been followed in respect to scientific names and order of listing; common names are as given in Alexander (1954).

Puffinus pacificus. Wedge-tailed Shearwater. Recorded on 10 days in the course of the eastbound leg, including a flock of 20 on October 6. Individual birds came aboard the ship on October 4 and 13 A total of eight was seen on October 24 just off Manzanillo, and one was recorded on October 27.

Puffinus griseus. Sooty Shearwater. This completely dark shearwater replaced the very similar Christmas Shearwater in the northeastern portion of the cruise track. It was recorded on October 13, 14, and 15 near 10°N, and again on October 24, 25, and 26, all in the general area southwest of Manzanillo. One bird was seen on November 4 near 7°S, 120°W.

Puffinus nativitatis. Christmas Shearwater. Observed on September 29 and 30 and daily from October 5 to 10 between 141° and 128°W. It was not identified again until November 13 when we had reached 129°W on the west-bound leg. Thereafter it was seen irregularly in the general area north of the Marquesas Islands, including one flock of about 20 recorded on November 18. It became far more abundant near and just north of Christmas Island and was last recorded on December 12 just north of Palmyra Island. On Motu Tabu in Christmas Island lagoon, this species was observed nesting in numbers. Many of the shallow nesting burrows or depressions contained an egg, and several half-grown chicks were seen.

Puffinus opisthomelas. Black-vented Shearwater. First recorded on October 4 when one came aboard the ship. Eight were observed on October 6, and thereafter occasional individuals were seen until October 26, all north of 9°N.

Puffinus assimilis. Dusky Shearwater. Recorded on October 24 and 25, just off Manzanillo, including a flock of about 24 individuals on the 24th, most of which were identified as this form.

Puffinus lherminieri. Audubon Shearwater. Recorded on November 23 and 25 and December 1 in the immediate vicinity of the Marquesas Islands. Several were seen on December 9 within a few miles of Christmas Island.

Pterodroma rostrata. Tahiti Petrel. On November 29 some Marquesan boys brought a bird of this species to the ship while at anchor in Taa Huku Bay, Hiva Oa Island. They stated it had been taken from a burrow on Hiva Oa that same morning. It was identified as this species, rather than *P. alba,* by the large bill, the complete absence of any white flecking on the throat, and by the entirely black outer toe. The bird was photographed and later released. Another bird, probably of this species, but possibly *P. alba,* was seen from the ship on November 30 while still close to Hiva Oa.

Pterodroma alba. Phoenix Petrel. Recorded on September 29 near 6°N, 154°W, and again on December 5 near 1°N, 149°W. The species was abundant on and near Christmas Island, and it was seen frequently in flight over both the lagoon and the land areas of the atoll. On Motu Tabu, Christmas Island, many were observed in and near burrows, and although most nests contained a single egg, no chicks were found. No birds were seen over the ocean out of sight of the atoll, except the two already noted.

Pterodroma phillipii. Kermadec Petrel. Recorded in the course of the eastbound leg on October 5, 7, and 9 near 10°N between 141° and 131°W. Three birds, probably of this species, were seen November 4 near 7°S, 120°W. Distinguished from the Herald Petrel (*P. heraldica*) by the larger body size and the distinct white area toward the tip of the under surface of the wings.

Pterodroma phaeopygia. Hawaiian Petrel. This bird was observed more frequently throughout the cruise than any other species. It was first seen September 27 near 9°N, 155°W and from then until October 30 it was recorded on 24 out of 28 days at sea. Usually about one to three individuals were seen each day, although unusually large counts of nine birds each were noted on October 16, 26, and 28. It was not seen for four consecutive days (October 31 to November 3) at the extreme southeast portion of the cruise track, but scattered birds were seen again on 13 of the next 20 days, in equatorial waters between 120° and 140°W. This included three birds recorded November 22 on 140°W near 6°S. Most of a flock of 25 shearwaters seen on November 6 were thought to have been this species. Single birds were recorded on 4 of the 8 days between the Marquesas and Christmas Island, and one was seen on December 11 near Washington Island. This species is reported to breed only in Hawaii and the Galapagos Islands (Richardson and Woodside, 1954). However, we failed to record it in the Hawaiian area and it was not seen as we neared the Galapagos Islands.

Pterodroma cookii. Cook Petrel. Small, fast-flying, white-breasted petrels were seen on 19 days in the course of the westbound leg, between Manzanillo and Christmas Island. Fifteen birds were counted on October 25, just off the Mexican coast, but usually there were not more than one or two individuals sighted per day. They were also recorded on four days on the eastbound leg (October 1, 3, 9, and 12). Most of these were thought to be *P. cookii* since the crown appeared gray, concolor with the gray of the upper back, as described by Murphy (1936:720). On the basis of the known range (Murphy, 1929; Jespersen, 1932–33) of these small "gadfly" petrels, many of the examples sighted may have been the Gould Petrel.

Pterodroma leucoptera. Gould Petrel. On the eastbound leg of the cruise this petrel was recorded on September 27 and 30 near 155°W and 151°W, respectively, between 8°N and 9° N.

Bulweria bulwerii. Bulwer Petrel. Fairly abundant around the Marquesas Islands. Many were seen while traveling between islands, but only one was recorded away from the island group; this was seen on November 18 near 4°N, 139°W.

Fregetta grallaria. White-bellied Storm-petrel. Three birds seen on November 3 and single birds observed on November 17 and December 1.

Nesofregetta albigularis. White-throated Storm-petrel. One bird observed on October 6 near 10°N, 138°W. The species was not sighted again until we reached the Marquesas, where single birds were observed on three days. On December 1, one came aboard and was banded and released. One was seen on December 8 as we approached Christmas Island, and several were observed on December 9 over Christmas Island lagoon and also in the ocean nearby.

Oceanodroma castro. Madeiran Storm-petrel. *Oceanodroma leucorhoa.* Leach Storm-petrel. Small, white-rumped petrels were seen east of 144°W almost daily from October 4 to November 20. One bird came aboard the vessel on October 6 and was tentatively identified in the hand as *O. castro.* They were not recorded on November 3, 4, or 5 at the extreme southeast portion of the cruise track, but otherwise during this period we never failed to sight them for more than one day consecutively. From October 31 to November 19, on both sides of the Equator between 113°W and 140°W, a total of 11 storm-petrels came aboard the ship during the evening hours. These birds all belonged to the same species. Seven were captured, banded, and released, and one was preserved as a specimen which was later sent to the United States National Museum and there identified as *O. leucorhoa.* After leaving the Marquesas, storm-petrels were recorded only on December 6, 7, and 8 southeast of Christmas Island, and on December 11 between Christmas and Palmyra. Most of the storm-petrels observed from the vessel during daylight hours appeared to have a broad rectangular rump patch similar to the example of *O. castro* which was examined in the hand. A few were observed to have markedly forked tails.

Oceanodroma melania. Black Storm-petrel. Seen only close to the Mexican coast. One recorded on October 19 and three together on October 24.

Phaëthon aethereus. Red-billed Tropic-bird. Seen on October 19 and 24 close to the Mexican coast.

Phaëthon rubricauda. Red-tailed Tropic-bird. The only species of tropic-bird regularly seen more than 200 miles from land. Infrequently sighted on the eastbound leg to the east of 150°W, but after leaving Manzanillo individuals and pairs were seen frequently from October 26 to November 20, and again from December 4 to 15. Not recorded in or near the Marquesas group. On Motu Tabu, in Christmas Island lagoon, about ten nests were located, each containing an egg or a chick. The chicks were in all stages from very young to nearly full grown.

Some individuals in the open ocean either lacked the long central tail feathers altogether, or had two very small white feathers protruding from the tail. While these individuals did not have the typical mottled pattern of young birds, they sometimes appeared dingy on the back and usually the bill was darker than normal. They were usually seen in the company of a bird in typical adult plumage.

Phaëthon lepturus. White-tailed Tropic-bird. Recorded near the Hawaiian Islands on September 24 and December 15 and 16. Common in and around the Marquesas Islands.

Fregata magnificens. Magnificent Frigate-bird. Common in Manzanillo harbor, and individuals seen at sea on October 24 and 25 were probably this species. A flight of six birds seen on October 29 was also presumed to be this species.

Fregata minor. Great Frigate-bird. Common in and around Christmas Island.

Fregata ariel. Lesser Frigate-bird. Frigate birds were fairly common in the Marquesas Islands, and every adult male definitely identified belonged to this species.

Pelecanus occidentalis. Brown Pelican. Common in and near Manzanillo.

Sula nebouxii. Blue-footed Booby. Several seen on November 19 just off the Mexican coast, but they were much fewer in number than *S. leucogaster.*

Sula dactylatra. Blue-faced Booby. Four birds recorded on September 28 and 29 between 5°N and 3°N, 110°W. Not definitely identified again until December 8 when we were approaching Christmas Island. Many were seen on and around Christmas Island on December 9, and several were recorded over the ocean between Christmas and Palmyra. One was seen on December 14 near 12°N, 160°W.

Sula sula. Red-footed Booby. Common around the Marquesas Islands, where all individuals sighted were in the brown phase. At Christmas Island, most of the birds had brown wings and back, but were otherwise white. Birds seen between Christmas and Palmyra were in the white phase typical of the Hawaiian Islands.

Sula leucogaster. Brown Booby. Abundant close to the Mexican coast and also around the Marquesas Islands. Several were seen at Christmas Island. None recorded at sea more than 100 miles from land.

Pluvialis dominica. Golden Plover. One observed in flight at sea on September 28.

Arenaria interpres. Ruddy Turnstone. On October 3, near 10°N, 146°W one circled the ship for about 10 minutes. A flock was observed on October 19 near the Mexican coast.

Phalaropus fulicarius. Red Phalarope. Four unidentified phalaropes were recorded on October 19 just off the Mexican coast, and four more were observed in the same general area on October 24. Again, four were seen on November 8, near 4°N, 120°W in association with a marked convergence or "front" in the upper layer of the ocean. On the following morning, still in the convergence zone, an individual phalarope was observed very close to the ship and identified as this species.

Catharacta skua. Great Skua. A bird identified as this species passed close by the ship on November 13, near 1°S, 129°W.

Stercorarius pomarinus. Pomarine Jaeger. Jaegers probably of this species were recorded occasionally on all portions of the cruise track, between September 29 and December 6.

Larus sp. One gull, possibly *L. californicus* in second-year plumage, followed the ship briefly on October 13, more than 1000 miles from the Mexican coast.

Sterna sp. Two or three large flocks of medium-sized white terns with light gray mantles were observed together on October 24, about 50 miles off the Mexican coast.

Sterna fuscata. Sooty Tern. Observed far more frequently than any other tern. Recorded on only four days on the eastbound leg, but abundant close to the Mexican coast. Between Manzanillo and the Marquesas it was seen occasionally, including a flock of 25 to 30 birds on November 4 and a flock of 14 birds on November 8 in association with a convergence front in the upper layers of the ocean. The species was abundant in and around the Marquesas and was observed daily at sea between the Marquesas and Palmyra Island. It was not seen after December 11.

Thalasseus bergii. Crested Tern. Nine individuals recorded on Christmas Island, on the same sand bar at the lagoon entrance where King (1955) found them in 1953.

Procelsterna cerulea. Blue-gray Noddy. Common in and near the Marquesas and Christmas Island. On Motu Tabu in Christmas Island lagoon several eggs were found.

Anoüs stolidus. Common Noddy. Several birds of this species were seen in the Marquesas Islands and on Christmas Island. In addition, two birds were recorded at sea on October 10 near 10°N, 128°W.

Anoüs minutus. White-capped Noddy. Common in and near the Marquesas and Christmas Island. On Motu Tabu in Christmas Island lagoon nesting was nearly completed and only a few nearly full grown young were seen.

Gygis alba. White Tern. Abundant in and around the Marquesas Islands. Although many were observed on Nukuhiva Island, none was captured or collected so that the form *G. a. microrhyncha* was not definitely identified. This species was also abundant on Christmas Island, where on December 9 nesting was in progress and all stages from eggs to nearly grown chicks were seen. Recorded at sea each day between Christmas and Palmyra islands.

Unidentified Ducks. A flock of about 12 ducks flying south was recorded on October 5. Individual ducks were observed on October 6, 9, 10, and 27. None was close enough to identify the species.

SUMMARY AND CONCLUSIONS

Forty species of sea birds, principally shearwaters, petrels, storm-petrels, tropic-birds, frigate-birds, boobies, and terns, were sighted on the "Eastropic" cruise of the M/V *Hugh M. Smith* to the central and eastern tropical Pacific.

Scattered sea birds were most abundant along the northern boundary of the Countercurrent at about 10°N latitude. The largest numbers occurred near 110°W longitude, influenced no doubt by the nearness of the Mexican coast; and on 140°W longitude a second area of high abundance was found which may be related to the shallow thermocline, high phosphate concentrations, and rich zooplankton conditions characteristic of this region.

There is some indication that in the daylight hours scattered birds were most numerous during the late afternoon period. Increasing cloudiness had no effect on the numbers of birds sighted; but when the wave height increased, fewer birds were recorded.

There was little or no evidence that birds occurred in greater frequency in areas of marked temperature change in the sea surface.

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United States Fish and Wildlife Service, Honolulu, Territory of Hawaii, August 3, 1956.

THE CONTROL OF THE UPSTREAM MOVEMENT OF FISH WITH PULSATED DIRECT CURRENT[1]

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ABSTRACT

Alternating-current electromechanical devices installed in the mouths of streams have proved effective in stopping the spawning migrations of the parasitic sea lamprey *(Petromyzon marinus)* which has seriously damaged Great Lakes fisheries. In a few streams, excessive mortality has occurred to other fish at the alternating-current barriers. A direct-current unit was developed in an attempt to reduce this mortality. This direct-current "diversion device" consists of a row of suspended negative electrodes which begins at the end of a trap wing and extends across the river at a downstream angle of 45° and a series of pipes (positive electrodes) driven into the stream bank. A second array, consisting of horizontal pipes installed downstream and parallel to the suspended electrodes and connected to a series of rods driven into the bank near the positive electrodes, controls the electrical field and dissipates the collecting influence of the positive side of the circuit. The electrical field is established from the end of the trap wing to the opposite bank. Fish are diverted away from the negative electrodes and toward the bank near which the trap is located. The array is activiated by pulsated direct current of essentially square wave shape with pulses at a duty cycle of 0.66 and a repetition rate of 3 per second. Direct-current diversion devices were operated in conjunction with alternating-current barriers during 1956 in the Chocolay River, Marquette County, and the Silver River, Baraga County, Michigan.

A total of 15,814 fish comprising 21 species was handled at the Chocolay River with a mortality of 930, or 5.9 percent. If mortalities of fish moving downstream are disregarded, only 287, or 1.9 percent, of the fish moving upstream were killed in the Chocolay River.

In the Silver River, 78,648 fish comprising 21 species were taken from the trap of the direct-current diversion device. The total kill of fish moving upstream, including 289 sea lampreys, was 1,016, or 1.3 percent. This river had presented a serious problem in the operation of an alternating-current control device during previous seasons. In 1955, 85.5 percent of three important species of fish were killed at the control structure. During 1956, this mortality was reduced to 8.1 percent by the operation of the direct-current equipment.

INTRODUCTION

The development and application of control methods to reduce stocks of sea lampreys in the Great Lakes is one of the major objectives of the Great Lakes Fishery Investigations. Several methods of sea lamprey control

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[1] This study was conducted under the direction of Leo F. Erkkila, Fishery Research Biologist, Marquette, Michigan.

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have been tested. Among these, alternating-current electrical barriers combined with mechanical traps, installed near the mouths of streams and rivers, have proved the most effective in preventing sea lampreys from reaching spawning grounds (Applegate, Smith, and Nielsen, 1952). However, an efficient electrical control device not only must block or destroy sea lampreys, but also must inflict a minimum of damage on fish.

Excessive mortality of fish at electrical barriers has been encountered in a few streams (Erkkila, Smith, and McLain, 1956). Attempts to reduce this mortality have usually entailed modifications in the electrical fields and improvements to trapping facilities. The possibilites of using direct current in conjunction with, or as a substitute for, alternating current are being explored as an additional solution to this problem.

Preliminary work with direct current was done at the Fish and Wildlife Service's Hammond Bay Fishery Laboratory near Rogers City, Michigan (McLain and Nielsen, 1953). Laboratory tests proved that some fish could be made to swim to the positive electrode when subjected to the right type of current (see Applegate, Macy, and Harris, 1954, for literature pertaining to this principle). Preliminary field tests brought out some of the problems in the use of direct current as a leading or capturing device.

The present investigation began in the spring of 1955 with field tests in the Chocolay River, Marquette County, Michigan. Attempts were made to fish the full width of the river with a series of direct-current electrical feilds. These fields consisted of two leading, or guiding, fields and a diversionary field. The diversionary field, at negative potential, blocked an area in the center of the river. The leading fields were created from each end of the diversionary field to a trap, or combination of traps, installed near each bank. The positive electrodes were incorporated into the traps.

During periods of observation careful counts of all fish entering the electrical fields and their reactions were recorded. Only 3 percent of the fish penetrating the leading field failed to exhibit a good leading response and managed to leave the area. Thirty-eight percent were forced to enter a trap; 50 percent led to the entrance and were overcome, and 8 percent led to the sides of the trap. Fish failing to enter the trap and those leading to the sides (58 percent) were considered to represent potential mortality.

The two major factors which restricted the success were our inability to establish a uniform voltage gradient, and the failure to design a trap which would retain fish but allow compartively easy entrance. The lack of uniformity of the voltage gradient was by far the more important. Fish encountering voltages of the proper level midway between electrodes were confronted with a more intense field as the positive electrodes were approached. Many had difficulty negotiating the restricted opening of the trap funnels because their movements were involuntary.

Observations of the reactions of fish to various components of the electrical fields led to the development of the device described here. By the time the present device was fully evolved in 1955, the movements of fish at the experimental site had nearly ceased; therefore, results were inconclusive but they indicated the desirability of further tests. This paper describes the device and the results obtained from experimental units operated in the Chocolay River and the Silver River, Baraga County, Michigan, during the 1956 season.

The common and scientific names of the species of fish mentioned in this report are as follows:

Sea lamprey	*Petromyzon marinus*
Silver lamprey	*Ichthyomyzon unicuspis*
Rainbow trout	*Salmo gairdneri*
Brown trout	*Salmo trutta*
Brook trout	*Salvelinus fontinalis*
Smelt	*Osmerus mordax*
White sucker	*Catostomus commersoni*
Longnose sucker	*Catostomus catostomus*
Silver redhorse	*Moxostoma anisurum*
Golden shiner	*Notemigonus crysoleucas*
Creek chub	*Semotilus atromaculatus*
Pearl dace	*Semotilus margarita nachtriebi*
Common shiner	*Notropis cornutus*
Longnose dace	*Rhinichthys cataractae*
Brown bullhead	*Ictalurus nebulosus*
Northern pike	*Esox lucius*
Burbot	*Lota lota*
Trout-perch	*Percopsis omiscomaycus*
Ninespine stickleback	*Pungitius pungitius*
Yellow perch	*Perca flavescens*
Logperch	*Percina caprodes*
Smallmouth bass	*Micropterus dolomieu*
Pumpkinseed	*Lepomis gibbosus*
Rock bass	*Ambloplites rupestris*
Freshwater sculpins	*Cottus bairdi* and *cognatus*

THE DIRECT-CURRENT DIVERSION DEVICE

The device is based on the principle that a unidirectional movement of fish is induced by pulsated direct-current electricity. The movement is toward the positive electrode, or away from the negative electrode. Since prolonged proximity to the positive electrode results in undesirable electrical narcotization of fishes, the device is designed to establish in the water only the negative half of a guiding field and thus to eliminate any collecting or narcotizing influence of a positive electrode. The device acts therefore as a diversionary unit.

The equipment is a "grounded system" in which the negative side of the circuit is placed in the water while the positive side is grounded to electrodes driven into the stream bank. The first model as installed in the Chocolay River consisted of:

1. A trap (4 by 4 by 6 feet, covered with ½-inch-mesh hardware cloth) placed against the west bank of the stream—a 10-foot wing, also covered with hardware cloth, extended downstream from the trap at an angle of 45°;
2. A suspended row of ½-inch galvanized-pipe electrodes spaced 6 inches apart, beginning 20 inches from the end of the wing and running completely across the river at the same angle (negative electrode array);
3. A row of copperweld ground rods, 6 to 8 feet long and spaced 6 feet apart driven into the west bank of the stream in a line parallel to the shore about 8 feet from the water's edge and two ground rods placed in the bank near the trap (positive electrodes);
4. A submerged horizontal pipe, 1½ inches in diameter, suspended at mid-depth or placed on the bottom of the stream 5 feet downstream from and parallel with the suspended electrodes—the pipe was connected at intervals to ground rods driven into the stream bottom and to a row of ground rods in the west bank 4 feet streamward of and parallel to the original row (in further discussion this unit is termed the "control array"); and
5. A power supply to furnish pulsated direct current. The negative side of the power supply[2] is attached to the row of suspended electrodes and the positive side is connected to the row of ground rods farthest from the stream bank. The power unit produced pulses at a duty cycle of 0.66, a repetition rate of three pulses per second, and an essentially square wave shape. Although other investigators (Groody, Loukashkin, and Grant, 1952: Haskel, MacDougal, and Geduldig, 1954; Houston, 1949; Raymond, 1956; and Trefethen, 1955) have reported various pulse durations, repetition rates, and wave shapes, response by the species of fish involved in the present study has been satisfactory with the type of current described above.

The control array (see item 4 above) served two functions: it extended the electrical field at a higher intensity for a desired distance from the negative electrodes, and it eliminated or greatly reduced the electrical field near the west bank and the entrance of the trap. Without the control array a strong field existed near the cathodes but 1 foot distant from them only 0.18 volt per inch was measureable, when 110 volts were applied to the array. The control array increased the voltage gradient to 0.35 volt per inch 1 foot from the cathodes, even when the applied voltage was reduced to 100 volts. At 4 feet from the electrodes the gradient at median water depth was twice that which existed without the control array (Figure 1). Alhough the characteristics of the electrical field were considered satisfactory with the horizontal control array pipe on the stream bottom, even

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[2] The electrical equipment is basically the same as described by McLain and Nielsen (1953).

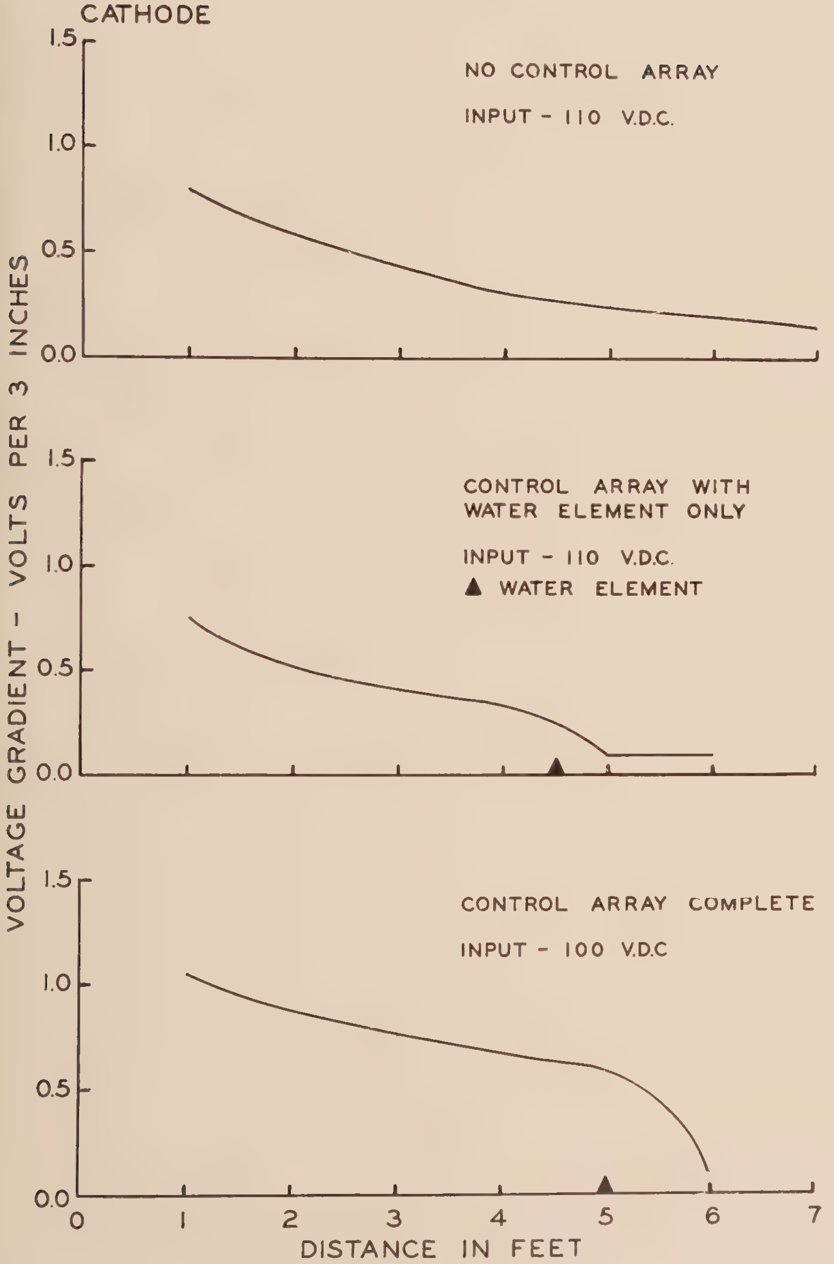

FIGURE 1.—Voltage gradients in volts per 3 inches as influenced by the control array of the direct-current diversion device.

better performance was obtained when the pipe was placed at mid-depth. A 1½-inch pipe provided sufficient surface for the horizontal element of the array in water depths up to 4 feet when suspended at mid-depth. In the two experimental units operated in 1956, two rows of 1¼-inch pipe were used. One row was laid on the bottom and the other was mounted approximately 18 inches above the first. They were held in place by 8-foot steel fence posts driven into the bottom.

The correct spacing between various components of the array cannot be precisely predetermined. The array functions as a "voltage divider" so that a portion of the drop in the applied voltage occurs between the negative electrodes and the horizontal pipe of the control array and a portion between the units on the bank. The extent of voltage drop between each depends on the total applied voltage and the resistance of the water and the soil. For satisfactory operation it is important that the spacing between the rows of ground rods in the bank produce a voltage drop great enough to eliminate any collecting influence at the horizontal pipe downstream from the hanging electrodes, and that the spacing between the horizontal pipe and the hanging electrodes be sufficient to develop a field that controls fish moving into it. On the Chocolay River in 1956, the horizontal pipe was placed originally 5 feet from the negative electrodes and later was moved to 6 feet. At the Silver River installation the spacing between the two originally was 5 feet and later was reduced to 4 feet.

The negative electrodes must provide a large amount of surface area to assure an even distribution of lines of force throughout the electrical field. As described in item 2, the original device had ½-inch pipes hung 6 inches apart. The two experimental models operated during 1956 used 1¼-inch pipes spaced 1 foot apart.

Requirements on placement and spacing are less exacting for positive than for negative electrodes. The number of electrodes used, or the amount of surface area required, in the positive array depends on the soil conditions. The unit as operated on the Chocolay River during 1956 had eight positive electrodes, ½-inch in diameter, and approximately 7 feet long. These were driven 2 feet apart in a line parallel to and about 8 feet from the water's edge. The Silver River device required 10 pieces of 1¼-inch pipe driven 10 feet to overcome the high resistance of the soil. As with the Chocolay unit, they were spaced about 2 feet apart and located about 8 feet from the water's edge.

As stated previously, the distance between each positive electrode and its corresponding bank electrode of the control array depends upon the soil resistance and that portion of the total voltage drop it is necessary to make in the bank to eliminate a collecting influence at the horizontal pipes of the control array in the water. The minimum allowable voltage drop in the bank is unknown. The original device dropped nearly 70 percent of the applied voltage in the bank with the spacing as described in item 4. The spacing between the positive electrodes and the bank elements of the control array of the two devices operated during 1956 was reduced to about 2 inches. This change reduced the voltage drop to 50 percent or less of the total applied voltage. The reduced spacing resulted in an increase in the percentage of voltage available to the water. It also reduced the resistance and allowed more amperes of current. Since the desired galvanotaxic response of a fish is not a factor of voltage or of amperage but of energy (Cattley, 1955), it was necessary to reduce the applied voltage. The modified device was not more efficient from the standpoint of power consumption as the increased amperage compensated the reduction of voltage and power consumption in terms of watts remained comparatively stable.

A minor but important component of the device not heretofore discussed is a "wing control" to regulate the electrical field between the end of the trap wing and the first negative electrode. Inasmuch as the metallic end of the wing is closer to the first negative electrode than to the horizontal pipes of the control array, a large concentration of lines of force exists at this point; the direction of flow is toward the end of the wing. Fish which enter this area are diverted toward the wing. Some of the fish move to the upstream side of the wing where they either manage to escape upstream or are held against the surface of the wing by the electrical stimulus. The wing control supplies a metal surface which attracts part of the electrical current moving to the wing and changes its direction to assure that the fish are diverted to the downstream side of the wing.

Two types of "wing control" have been installed. The first consists of bare copper wire attached to the end of the wing. The 1956 Chocolay structure had ¼-inch copper tubing. The wire extended to a point halfway between the first negative electrode and the end of the horizontal pipe of the control array.

In the second type, used in the Silver River, three lengths of 1¼-inch pipe were driven along the line followed by the wire. The first pipe was about 6 inches from the wing and the succeeding pipes were spaced approximately 1 foot apart. The pipes were long enough to be driven securely into the bottom of the river and extend above the surface of the water. They were connected electrically to each other and to a fourth pipe driven about 3 inches from one of the positive electrodes. This arrangement functioned exactly as the control array. Both methods of controlling the electrical field at the end of the wing were successful.

The complete device is illustrated diagrammatically in Figure 2. The electrical field is established from the end of the trap wing to the opposite bank of the river. The inside of the trap and the area between the trap wing and the bank are free of any electrical current. The device simply turns back or diverts fish from the suspended negative electrodes to the bank along which the trap is located. The fish are free to enter the trap or return downstream.

Inasmuch as the electrical energy necessary to control sea lamprey move-

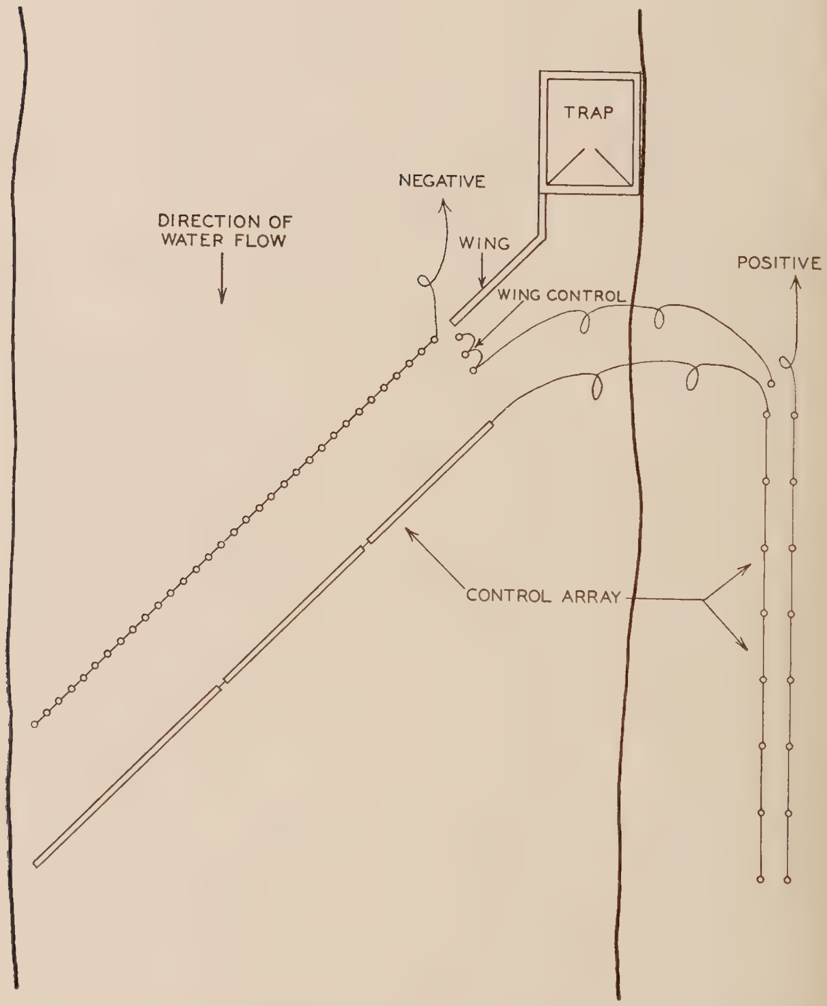

FIGURE 2.—A diagrammatic sketch of the trap and electrode arrays of the direct-current diversion device.

ments is greater than that required to control movements of fish, alternating-current control structures were installed immediately above the direct-current diversion devices.

Power Requirements of the Direct-current Diversion Device

The operation of many alternating-current control devices had indicated that each river has its own characteristics which greatly influence the efficiency of an electrical barrier, (Erkkila, Smith, and McLain, 1956). What changes in power demands or modifications to the electrode array of a direct-current diversion device would be necessary in other rivers is unknown. However, the structures as operated in the Chocolay and Silver Rivers functioned at nearly the same power levels.

Inasmuch as voltage, voltage gradient, or amperage, considered individually, are undependable as criteria of the efficiency of an electrical field, energy expressed in watts was used as the basis for establishing the intensity of the electrical fields.

Fortunately the design of the device is such that it functions satisfactorily over a fair range of power applied to the water. Since power in watts is the product of the voltage and amperage, power remains constant only while they remain constant or undergo compensating changes. Neither voltage nor amperage can be controlled exactly in the equipment. Amperage is dependent on the input voltage and the total resistance in the circuit. The resistance between the electrode arrays of the direct-current structures is not constant due to almost continual fluctuations of water conductivity, water level which regulates immersed electrode surface area, and, to a much lesser degree, fluctuations of soil conductivity with changes in moisture content. A change in the resistance of either the water or soil alters the amperage and also causes the voltage drop in the water to change relative to that in the bank.

Although 400 watts applied to the water was considered desirable, the devices functioned satisfactorily over a range of 300 to 500 watts. The voltage input ranged from about 120 to 200 volts direct current at 4 to 6 amperes. The voltage and amperage varied in a relationship that resulted in a total power consumption (including losses in transformers, rectifiers, . . .) of about 900 watts for each device.

Experimental Sites

The Chocolay River is 50 feet wide and well contained between its banks except for periods of extreme flood. Maximum depth is 2 feet during low-water stages and approximately 6 feet at flood stage. The bottom is predominately soft, shifting sand overlying clay. Water velocities varied from 1.5 to 2.5 feet per second. From early spring until mid-summer, the water conductivity ranged from 63.78 to 136. 50 micromhos at 18°C.[3]

The Silver River is 70 feet wide and about 3 feet deep during low-water periods. Its bottom is also soft, shifting sand. During flood periods, water velocities of 2 feet per second were measured. Velocity drops to 0.5 foot per second and during late May, June, and July almost constantly recurring periods of reversing flow occur because of seiche in Lake Superior. The maximum rises in water level and upstream velocity due to seiche action during the 1956 season were 0.95 foot and an estimated 2 feet per second, respectively. Lake seiche and low water velocities were major factors contributing to the inefficiency of the alternating-current control device operated on the Silver River during preceding seasons. Water conductivity varied during the period of operation from 30.70 to 104.82 micromhos at 18°C.

EXPERIMENTAL PROCEDURE

The direct-current diversion device was designed to operate downstream from, but in conjunction with, an alternating-current barrier. Therefore it was necessary to distinguish between fish moving downstream through the alternating-current electrical field and those moving upstream from the lakes if an adequate evaluation of the direct-current installation was to be made. The timing of upstream migrations of fish into Lake Superior streams has been well established by weir operations over the past 6 years. Consequently, the experimental direct-current devices were installed before any migration started except that of rainbow trout. Few fish except rainbow trout could be expected to move downstream until some had been passed upstream through the traps. All large fish released upstream from the trap at the direct-current device were marked by removing a portion of the right pectoral fin so that they could be identified if taken or killed on their downstream migration through the alternating-current field. The traps were emptied daily by a service crew which also marked fish and searched the stream in the vicinity of the barriers for dead fish. During the periods of heavy fish movement, the Chocolay River was patrolled for 1 mile downstream from the control site and the Silver River was covered from the control site downstream to its mouth, approximately ¾ mile. Recoveries of dead fish were recorded by species, fin mark, and location (*i.e.* alternating-current field, direct-current field, or downstream).

Water temperature, water level, and electric power consumption were recorded daily. Water conductivity was measured almost daily and water samples were collected for analysis of electrolytic content. Water velocities were checked with each appreciable change in volume of flow.

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[3] Water conductivity measurements were taken with a conductivity bridge, Industrial Instruments, Inc., Model RC-16B-1. The formula used to correct conductivity readings to 18°C. is as follows:

$$C_{18} \quad \frac{1{,}000{,}000}{Rt \times [1 + (0.02 \Delta t)]}$$

Where C_{18} equals calculated conducitivity at 18°C. in reciprocal megohms; *Rt* equals resistance of water at temperature *t*; Δt equals $t - 18$; and *t* equals temperature at which the measurement was made.

TABLE 1.—*Records of fish taken in the trap of the direct-current diversion device and fish killed at the Chocolay River sea lamprey control site during the 1956 season*

[The table does not include mortalities of fish marked and passed upstream. Neither does it include adjustment covering periods of malfunction of the direct-current unit]

Species	Total number of fish handled	Number of fish trapped	Number of fish killed				Percentage kill of total handled
			A.C. field	D.C. field	Downstream	Total	
Sea lamprey	6,502	6,054	395	46	7	448	6.9
Longnose sucker	5,217	4,980	40	67	130	237	4.5
White sucker[1]	1,141	1,113	18	3	7	28	2.5
White sucker[2]	733	730	3	..	..	3	0.4
Rainbow trout[3]	114	108	1	2	3	6	5.3
Rainbow trout[4]	434	239	193	2	..	195	44.9
Smelt	713	713	..	..	..	..	..
Pumpkinseed	402	402	..	..	..	..	..
Brown bullhead	182	182	..	..	..	..	..
Creek chub	178	174	3	1	..	4	2.3
Miscellaneous[5]	198	189	8	1	..	9	4.5
Totals	15,814	14,884	661	122	147	930	5.9

[1] Spawning migrants over 9 inches, total length.
[2] Under 9 inches, total length.
[3] Spawning migrants over 12 inches, total length.
[4] Immature rainbow trout which represent a downstream movement. This accounts for the large number killed in the alternating-current field.
[5] Miscellaneous includes: brook trout, brown trout, burbot, longnose dace, northern pearl dace, freshwater sculpin, ninespine stickleback, yellow perch, and rock bass.

OPERATION OF DIVERSION DEVICES

Th Chocolay River device was operated from April 13 to July 25 and the one in the Silver River from April 20 to June 30, 1956.

CHOCOLAY RIVER

A total of 15,814 fish comprising 21 species were handled at the Chocolay River. The mortality was 930 fish, or 5.9 percent (Table 1). In addition, 220 of the marked fish released upstream from the traps of the direct-current structure were killed. The marked fish were subjected to the alternating-current field on their return downstream. Included in the 930 individuals killed were 195 small rainbow trout, of which 193 were found in the alternating-current field. They were killed as they moved downstream. An area near the bank which had very low water velocities accounted for a large portion of the young rainbow trout killed.

The kill also includes 448 sea lampreys of which 395, or 82.2 percent, were found dead in the alternating-current field. The direct-current voltages were not adjusted to control sea lampreys. However, 93.1 percent of all the sea lampreys moving up the Chocolay River were trapped by the direct-current unit.

Contributing to the mortality were 13 intervals of time during which the direct-current device was inoperative or functioning unsatisfactorily. It was impossible to determine accurately the mortality attributable to the malfunctions of the direct-current unit. Disregarding periods of malfunction, but eliminating mortalities of downbound fish and of sea lampreys, the total kill of fish moving upstream was only 287 or 1.9 percent of the total.

Of the total number killed, including marked fish, 69 percent were found in the alternating-current field. Of the remaining 356 fish, the number killed by exposure to the alternating-current field is unknown. It can be assumed that some of those found dead in the direct-current field had floated down from the alternating-current field.

SILVER RIVER

In the Silver River, 78,648 fish comprising 21 species were taken from the trap of the direct-current diversion unit (Table 2). The kill of fish at and below the control site totaled 1,228, including 289 sea lampreys and 212 marked fish. Runs of smelt and trout-perch into Silver River were much larger than those in the Chocolay River. The direct-current diversion

TABLE 2.—*Records of fish taken in the trap of the direct-current diversion device and fish killed at the Silver River sea lamprey control site during the 1956 season*

[The table does not include mortalities of fish marked and passed upstream. Neither does it include adjustment covering periods of malfunction of the direct-current unit]

Species	Total number of fish handled	Number of fish trapped	Number of fish killed				Percentage kill of total handled
			A.C. field	D.C. field	Down-stream	Total	
Sea lamprey	857	568	150	138	1	289	33.7
Longnose sucker	74	70	..	4	..	4	5.4
White sucker[1]	4,205	4,057	69	61	18	148	3.5
White sucker[2]	271	270	1	..	..	1	0.4
Rainbow trout[3]	50	45	3	2	..	5	10.0
Rainbow trout[4]	69	62	5	2	..	7	10.1
Smelt	51,774	51,417	357	..	..	357	0.7
Trout-perch	20,073	19,898	175	..	..	175	0.9
Logperch	1,705	1,680	25	..	..	25	1.5
Common shiner	182	182					..
Creek chub	158	158	..	..	..	..	..
Miscellaneous[5]	246	241	5	..	..	5	2.0
Totals	79,664	78,648	790	207	19	1,016	1.3

[1] Spawning migrants over 9 inches, total length.

[2] Under 9 inches, total length.

[3] Spawning migrants over 12 inches, total length.

[4] Under 12 inches, total length.

[5] Miscellaneous includes: brook trout, silver redhorse sucker, smallmouth bass, yellow perch, rock bass, brown bullhead, burbot, longnose dace, golden shiner, freshwater sculpin, and silver lamprey.

device handled the very large smelt run excellently. Mortality due to electrical shock was insignificant in relation to the large number of fish. Only 357 smelt were killed while 51,417 were trapped. More smelt would have been taken but the catch was limited by the capacity of the trap.

Mortality to trout-perch was also very low—175 dead while 19,898 were caught in the trap.

Disregarding marked fish that were killed while moving downstream, 1,016 (1.3 percent) of the total number of fish handled were killed. Contributing to this mortality were seven periods of time during which the direct-current unit was inoperative or functioning improperly. Usually it was impossible to determine accurately the mortality attributable to equipment failure. However, three of the seven periods of malfunction are believed to be directly responsible for the deaths of two of the five rainbow trout and 69 of the 148 white suckers.

During the operation of an alternating-current barrier on the Silver River in 1955, mortalities were: large rainbow trout, 90.0 percent; longnose suckers, 72.1 percent; and white suckers 85.5 percent. The 1955 mortality records do not indicate the direction of movement of the fish at time of death. In 1956, when the direct-current diversion device was in operation, the mortality from all sources was: large rainbow trout, 15.1 percent; longnose suckers, 10.3 percent; and white suckers, 8.0 percent (Table 3). If it is assumed that all other factors were equal in the two seasons of operation, the mortality of the three species in the Silver River was reduced from 85.5 to 8.1 percent by the diversion unit.

FACTORS OF MORTALITY IN THE OPERATION OF THE DIRECT-CURRENT UNITS

The operation of the direct-current units drastically reduced, but did not eliminate, mortality of fish ascending the Chocolay and Silver Rivers. Some of the factors which contributed to the kill of fish were determined

TABLE 3.—*Comparison of fish mortalities in the Silver River during the 1955 season with the operation of a standard alternating-current barrier and the 1956 season with the experimental direction-current diversion device operated in conjunction with the alternating-current control*

Species	1955			1956		
	Number trapped	Number killed	Percentage killed	Number trapped	Number killed[1]	Percentage killed
Longnose sucker	38	98	72.1	70	8	10.3
White sucker	469	2,877	86.0	4,057	353	8.0
Rainbow trout	3	27	90.0	45	8	15.1

[1] The 1956 kill includes marked fish (fish moving back downstream). For the 1955 data it can be assumed that a few of those fish trapped and released upstream contributed to the mortality on their return. It is obvious from the figures that their contribution was not great.

is to divert the upstream movement of fish the direct-current diversion device should be highly satisfactory. At its present stage of development, the equipment cannot be used as a sea lamprey control unit without an alternating-current unit upstream from it because of the possibility of escapement of sea lampreys. It does provide an effective means of protecting and handling migrations of useful fish occurring at the same time as the sea lamprey runs.

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A Device for Rapid Conversion of Titration Values to Salinity

The conversion of titration units to salinity units using the Knudsen table[1] is slow and tedious when many data are being processed. I have made a study of the salinity equation which resulted in various graphical solutions. The graph shown in Figure 1 is probably the simplest of those derived, requiring only slight modification to convert it into a device that can be used to convert titration units into salinity units with a precision and speed far exceeding that obtained by using the Knudsen conversion tables.

THE SALINITY EQUATION

The salinity equation states that if the sample volume and reagent concentration remain constant, the following relationship exists: $\frac{Sp}{a} = k$, where S and p are the salinity and density, respectively, of the sample, a the volume of silver nitrate reagent necessary to titrate the sample, and k a constant. Since the equation contains two unknowns, S and p, it is solved by estimating values for S and p and then correcting the estimations with the aid of Knudsen's tables. The following example will illustrate this:

Let S = unknown salinity $= \frac{ak}{p}$

a = 17.000 double ml at an alpha[2] value of 0.000

k will be 1.85727 at the above alpha level

The p of the sample is estimated to be 1.00000. This estimation is purposely low. The use of a minimum estimate of 1.00000 will show that the maximum number of corrections necessary is four.

The first estimated S will therefore be $\frac{17 \times 1.85727}{1.00000}$ or 31.574‰.

The actual density corresponding to a salinity of 31.574 is 1.02537 (Knudsen tables). The second estimate will therefore be $\frac{17.000 \times 1.85727}{1.02537}$ or 30.792‰. Similarly, the third and fourth estimates will be 30.812 and 30.811‰ The fourth estimate is obviously the solution of the equation since the p value used in calculating S = 30.811 is the same as the Knudsen table value.

Usually two and never more than four estimates will result in an S value correct to the nearest .001‰. This procedure was used to calculate the values listed in Table 1.

A GRAPHICAL SOLUTION OF THE SALINITY EQUATION

A graphical presentation of the equation just described is shown in Figure 1. The horizontal axis makes up the salinity scale which is calibrated in parts per thousand (‰). The unit values are equally spaced. The vertical axis is calibrated in alpha units. The values on this axis, which are expressions of reagent concentration, cover a range from −.10 to +.10 and are equally spaced as shown. Should the silver nitrate reagent concentration fluctuate to an extent that would make this range impractical, it may be extended as desired. The titration scale is represented by the diagonal lines. The units on this scale are double milliliters. The scale is calibrated by calculating the salinity values that correspond to a titration reading at alpha levels of +.10 and −.10. The points representing the two values are connected with a straight line. Similarly, the pairs of values calculated for other readings are calculated and connected. Table 1 lists the titration readings and

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[1] Knudsen, Martin. 1901. Hydrographical Tables. Copenhagen and London.

[2] The term "alpha" is used to designate the concentration of the silver nitrate solution used in the titration of a salinity sample. The alpha is numerically equal to the chlorinity of Copenhagen Standard sea water minus the number of double milliliters required to titrate 15 ml of it.

Table 1. *Titration and salinity values used in constructing Figures 1 and 2.*

Titration (double ml)	Salinity at an alpha of		Titration (double ml)	Salinity at an alpha of		Titration (double ml)	Salinity at an alpha of	
	+.10	−.10		+.10	−.10		+.10	−.10
16.0	29.186	28.893	18.0	32.743	32.415	20.0	36.280	35.918
.1	.364	29.069	.1	.920	.590	.1	36.456	36.092
.2	.543	.246	.2	33.098	.766	.2	.633	.267
.3	.721	.423	.3	.275	.942	.3	.809	.442
.4	.899	.599	.4	.452	33.117	.4	.985	.617
.5	30.077	.775	.5	.629	.293	.5	37.161	.791
.6	.255	.952	.6	.806	.468	.6	.338	.965
.7	.433	30.130	.7	.983	.643	.7	.514	37.139
.8	.611	.304	.8	34.160	.818	.8	.690	.314
.9	.789	.480	.9	.337	.994	.9	.865	.488
17.0	.967	.657	19.0	.514	34.169	21.0	38.042	.662
.1	31.145	.832	.1	.691	.344	.1	.217	.836
.2	.322	31.008	.2	.868	.519	.2	.394	38.011
.3	.500	.185	.3	35.044	.694	.3	.569	.185
.4	.677	.360	.4	.221	.869	.4	.745	.358
.5	.856	.536	.5	.398	35.044	.5	.921	.533
.6	32.033	.712	.6	.574	.219	.6	39.097	.707
.7	.211	.886	.7	.751	.394	.7	.272	.880
.8	.388	32.063	.8	.927	.568	.8	.448	39.054
.9	.565	.239	.9	36.104	.743	.9	.623	.228
						22.0	.798	.402

corresponding salinity values that were used in the construction of the graph shown in Figure 1.

The dimensions between units has not been given since these can be varied depending upon the precision desired. A salinity value having a precision of ±.002‰ can be obtained if the distance between the .10 and −.10 alpha levels is 10 inches and also that this same distance separates the unit values on the salinity scale. A graph of these dimensions should have the unit values on both the salinity and titration axes divided into 100 equal parts. The smallest division on each of these scales will thus represent .01 of a unit.

CONSTRUCTION OF THE DEVICE

The device is a modified version of the graph just described. The only change consists of engraving the salinity scale on a strip of Lucite. This permits the salinity axis to be placed directly over the titration readings at any desired alpha level, thus permitting a rapid and accurate conversion of titration to salinity units. Figure 2 shows the complete device. For compactness it is made in two sections. Section A contains titration readings from 16 to 19 double ml and section B, 19 to 22. The corresponding sections of the salinity scale are engraved one over the other as shown. The vertical lines engraved on either side of the salinity scale are alpha guide lines. Their purpose is to prevent horizontal wandering of the salinity axis which would result in erroneous results. The range of titration values given is the same as that on a Knudsen Burette. The device, as described, may therefore be used to convert to salinity units any titration reading made with a Knudsen Burette.

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ON THE BRAMID FISHES OF THE GULF OF MEXICO

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On the Bramid Fishes of the Gulf of Mexico[1]

Giles W. Mead[2]

(Plates I-III)

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I. Introduction

Berg (1947: 474) includes the Pteraclidae and Steinegeriidae within the Bramidae. Although this arrangement may be a natural one, it is convenient here to follow the older classifications (*e. g.* Jordan, 1923: 181) and restrict the family to the genera *Brama, Taractes, Collybus* and *Eumegistus* and their synonyms. The Pteraclidae can be separated from the Bramidae by the longer bases and more anterior origins of their vertical fins. The Steinegeriidae includes only *Steinegeria rubescens* Jordan & Evermann (1887) of which only the type is known. This specimen was collected from the stomach of a red "grouper" which was caught in the Gulf of Mexico off Pensacola, Florida. It is in poor condition. Although the systematic position of this fish has not been established, its nearly vertical mouth, non-falcate dorsal and anal fins, the enlarged spines of the caudal peduncle and its nearly flat forehead separate it from *Taractes, Collybus* and *Brama* of similar size. *Steinegeria rubescens* will be the subject of a later paper, but is excluded from further comment here. A revision of the major classification of the bramid-like fishes is needed as badly as an analysis of the species and of the allometric growth associated with each.

The family, as so restricted, is represented in the Gulf of Mexico by two species: *Collybus drachme,* reported here for the first time from five off-shore localities; and a species of *Taractes* which I have called *T. longipinnis* and which is also first recorded here from the Gulf of Mexico. Although my material is inadequate for an analysis of the non-Gulf bramids, I have reviewed some of these in order to more clearly establish the identity of these Gulf of Mexico specimens.

"Length" as used here refers to standard length unless otherwise qualified. All measurements over 100 mm. were made with dividers and recorded in millimeters. Measurements between 5 and 100 mm. were made with dividers or dial calipers and recorded in half millimeters. Measurements of less than five mm. were taken with a calibrated ocular grid micrometer and were recorded to the nearest tenth of a millimeter.

II. Material and Acknowledgements

The first Gulf bramid which came to my attention was a *Taractes* 74.0 mm. in standard length (85 mm. fork length) taken by the U.S. Fish and Wildlife Service vessel *Oregon* at station no. 1043, an experimental tuna long-line station occupied on May 11, 1954, at Lat. 24° 16′ N., Long. 92° 00′ W. The specimen was found in the stomach of a yellowfin tuna (*Neothunnus albacares*) which was caught at a depth of less than 35 fathoms. The superficial fin membranes had been largely digested and some of the scales, head bones and fin rays were damaged, but the fish was otherwise in good condition.

Four adult *Taractes* were caught on later *Oregon* cruises. All were taken by the long-line at depths less than 35 fathoms. These specimens, 376, 371, 357 and 349 mm. in standard length (418, 413, 394 and 390 mm. in fork length respectively), came from the following two *Oregon* stations:

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[1] Contribution No. 973, Department of Tropical Research, New York Zoological Society.

[2] Ichthyological Laboratory U. S. Fish and Wildlife Service, U. S. National Museum, Washington 25, D. C.

1173 28° 54′ N. Lat., 88° 02′ W. Long., August 25, 1954

1317 28° 23′ N. Lat., 88° 43′ W. Long., June 11, 1955

Three of these fish are now in the collections of the U.S. National Museum, where they bear the catalogue numbers US 157793 and US 164328. These specimens, and the types of *Collybus drachme* and *Steinegeria rubescens,* were made available by Dr. Leonard P. Schultz, Curator of Fishes.

Ten juvenile specimens of *Collybus drachme* were collected at the following *Oregon* stations:

1043 24° 16′ N. Lat., 92° 00′ W. Long., May 11, 1954
1065 20° 34′ N. Lat., 95° 37′ W. Long., May 21, 1954
1377 27° 43′ N. Lat., 88° 43′ W. Long., August, 1955
1484 20° 50′ N. Lat., 95° 53′ W. Long., April 3, 1956
1486 22° 25′ N. Lat., 97° 00′ W. Long., April 4, 1956

I am indebted to Stewart Springer and Harvey R. Bullis, Jr., of the U.S. Fish and Wildlife Service, Pascagoula, Mississippi, and Edgar L. Arnold, Jr., of the U.S. Fish and Wildlife Service, Galveston, Texas, for the original preservation of this *Oregon* material.

G. E. Maul, Curator of Fishes in the Museu Municipal do Funchal, Funchal, Madeira, has kindly sent information regarding *Taractes* from Madeiran waters, and Dr. E. H. Bryan, Jr., Curator of Collections in the Bishop Museum, Honolulu, has sent a photograph of a cast of *Collybus drachme.*

Comparative bramid material from the Bermuda collections of Dr. William Beebe is now deposited in the Natural History Museum of Stanford University and was made available by Dr. George S. Myers.

The large *Taractes* from Nova Scotia which was reported by Bigelow & Schroeder (1929; MCZ no. 31598) and a photograph of a 570 mm. (fork length) Portuguese *Taractes* sent to these authors by Dr. Alfredo Ramalho were made available by Drs. Henry B. Bigelow and William C. Schroeder of Harvard University and the Woods Hole Oceanographic Institution.

III. *Taractes longipinnis*

Since my study of the six western North Atlantic *Taractes* listed above indicates that they are specifically identical regardless of certain differences among them, it is necessary to describe the more striking similarities and differences among the individuals of this series.

A 357 mm. Gulf specimen (Pl. I, Fig. 1) was first compared with the 618 mm. fish reported by Bigelow & Schroeder (1929) from Cape Sable, Nova Scotia. These fish differ in several respects. In the smaller fish the ventral fins originate under the middle of the bases of the pectoral fins, while in the Nova Scotia specimen their origins are beneath the anterior edges of the pectoral bases. The 357 mm. specimen also has relatively longer dorsal and anal lobes than the 618 mm. specimen, but, as Barnard (1948: 357) has suggested and as will be more fully discussed below, a progressive relative shortening of these fin lobes accompanies an increase in length of the adult fish. The 357 mm. individual also differs in having spines on the posterior body scales, and its eye is a little smaller and more nearly circular than that of the larger fish. Differences such as these accompany the development of *Brama raii* and are therefore of doubtful phylogenetic significance here. The fin membrane connecting the posterior dorsal and anal fin rays extends beyond the scaly sheath to the tips of the fin rays in the 357 mm. fish, while in the 618 mm. one this membrane is limited to the proximal two-thirds of the fin; it does not extend beyond the scaly sheath.

In all other details, such as the distinctive shape of the caudal fin, the presence and nature of the transverse caudal grooves which lie immediately in advance of the dorsal and ventral procurrent caudal rays, the dentition, the gill rakers and their minute accessory spines and tubercles and the general body form (exclusive of fins), the 357 mm. Gulf of Mexico individual is the same as that from Nova Scotia.

The differences between the 74 mm. juvenile (Pl. I, Fig. 2) and the 357 mm. adult are more striking. In pattern and number of scales, if not in the shape of the individual scale, the specimens are similar. The larger fish has 44 rows of scales between the upper margin of the gill opening and the base of the mid-caudal rays (where a sharp change in scale size occurs); the smaller one has 45. The number of longitudinal rows, from the mid-dorsal line in front of the origin of the dorsal fin to the mid-ventral line before the anal origin, is 27 in the larger fish and 26 in the smaller. The adult has 17 scales along the ventral mid-line between the origin of the ventrals and anus while the small fish has 15. Although the fin membranes are partially missing on the juvenile, traces of scale pockets similar to those of the adult can be found on the dorsal, anal and caudal fins. The distinctive axillary scales of both pectoral and ventral fins are alike in the two fish. The snout, branchiostegal membrane and rami of the lower jaw are equally scaleless in the two individuals.

The character of the individual scales, on the other hand, differs greatly between these two fish. Each body scale of the 74 mm. individual bears a strong spine, a characteristic of all known juvenile bramids and pteraclids. Considering only the spines along the median row of scales, those anterior to the 34th scale are directed backward; the last ten are directed forward. In the 357 mm. fish only the antrose spines on the posterior half of the body remain. All scales of Bigelow & Schroeder's 618 mm. fish are smooth. Each scale spine of the 74 and 357 mm. specimens originates near the center of the scale and protrudes through a notch in the posterior edge of the preceding scale. As the spines decrease in size anteriorly in the 357 mm. individual, these notches become less prominent. The same trend is apparent when a scale of the 74 mm. specimen is compared with one from the same point on the body of the 357 and 618 mm. specimens. Accompanying this change in scale form is a decrease in height of each scale. In the juvenile, the greatest height of a scale taken from the side of the body behind the pectoral fin is 3.5 to 4 times its greatest width, a ratio approaching the extremes encountered in such fishes as the grammicolepid zeoids and the bramid genus *Collybus*. The height of a scale from the same body location on the larger specimens is only one and one-half times its greatest width.

The premaxillary and mandibular teeth of the 357 and 74 mm. fish are very similar. The largest teeth of both jaws are the inner, anterior series of recurved canines. Some of the outer teeth of both jaws are directed slightly outward, a condition more apparent in the juvenile, in which the lips are somewhat macerated. The palatine teeth of the larger fish are better developed than those of the smaller. The vomer is toothless in both.

In number and shape of gill rakers and in position and degree of development of the accessory spines and hooks on each raker there are no significant differences between the 74 and 357 mm. fish. Exclusive of the rudiments, each has a raker count of 2+7. In addition, the epibranchial has three rudiments, which increase in length ventrally, and the hypobranchial has four. Each epibranchial raker has one or two medially-directed spines, while each raker of the ceratobranchial has three or four along its distal half. Each rudiment has a cluster of spines at its tip. In each fish there are also 4+9+4 spine-bearing tubercles on the inner side of the first gill arch. The 357 mm. specimen differs from the juvenile only in having 4 rather than 3 rudiments on the epibranchial, 6 instead of 4 on the hypobranchial, and in better developed spinules on the gill rakers and tubercles.

It is in the position and nature of the fins that the greatest differences between the juvenile and the adult are seen. Paramount among these is the nature of the dorsal and anal fins—falcate, with the rays filamentous and scarcely branched in the juvenile, less attenuated and with the rays branched in the larger fish (Table 1). The apparent difference in the position of the ventral fin could easily accompany growth from 74 to 357 mm., as could an increase in the amount of dermal material which supports the dorsal, anal and caudal lobes. A reduction in the length of filamentous fin rays is also undoubtedly a consequence of growth; such losses are known to occur during the development of many diverse species. Many fishes, conservative in form as adults, are adorned with various filamentous appendages as young. The change from lack of true branching in the fin rays of the juvenile cannot as readily be attributed to growth as these other fin differences, although juveniles of *Brama* have undivided or very weakly divided rays which later become fully branched (Lütken, 1880, pl. 4; Schmidt, 1918: 5).

No lateral line is visible on the 618 mm. specimen reported by Bigelow & Schroeder. The 357 mm. specimen, on the other hand, displays a series of about 13 modified scales which appear to represent a poorly-developed lateral line. This series begins above the upper end of the gill opening and arches posteriorly to a point below the middle of the dorsal lobe. A series of more typical lateral-line pores can be found on the corresponding scale row in the 74 mm. specimen. This series, also composed of 13 scales and terminating beneath the dorsal lobe, is slightly more arched than in the larger fish.

In both adult fish the premaxillary terminates anteriorly on a horizontal with the center of the eye and extends posteriorly to beneath the center of the eye. The free edge of the opercular bone is thin, entire and irregular in outline. The margins of the sub-, inter- and preopercle are membraneous. There are slight differences in degree of ossification and in the shape of the orbit. In both fish the orbit is nearly circular, while in Bigelow & Schroeder's 618 mm. fish the orbit is vertically elongate (the horizontal axis is contained 1.3 times in the vertical).

Both specimens have prominent transverse caudal grooves which lie above and below the caudal peduncle anterior to the procurrent caudal fin rays.

Although a direct comparison of the three additional Gulf of Mexico fish with the 618 mm. *Taractes* from Nova Scotia was not possible, no significant differences were found between these and the 357 mm. fish discussed above. The counts and measurements of the six western

TABLE 1.—COUNTS AND MEASUREMENTS OF SIX SPECIMENS OF *Taractes longipinnis* FROM THE WESTERN NORTH ATLANTIC

	Bigelow & Schroeder, 1929. Nova Scotia	*Oregon* Station 1173	*Oregon* Station 1173	*Oregon* Station 1112	*Oregon* Station 1317	*Oregon* Station 1043
Standard length (mm.)	618	376	371	357	349	74
Fork length (mm.)	670	418	413	394	390	85
Counts:						
Dorsal fin[1]	35	38½	37½	37½	37½	37
Anal fin[1]	28	29½	30½	29½	28½	28
Pectoral fin	20	22/22	21/21	21/20	21/21	20/21
Scales[2]	43	46	45	44	47	43
Gill rakers[3]	2+7	2+7	2+8	2+7	2+7	2+7
Measurements (% of standard length)						
Length of head	32.4	29.8	31.3	29.4	29.8	34.5
Length of snout	10.2	7.2	9.2	8.4	7.2	8.1
Length of premaxillary	14.7	14.4	15.1	14.6	13.8	16.9
Horizontal diameter of eye	6.6	5.9	6.5	5.9	6.3	10.8
Vertical diameter of eye	8.4	6.4	7.3	6.7	6.9	10.1
Width of interorbital	12.9	12.5	12.7	12.3	12.3	12.1
Greatest depth of body	52.1	54.5	55.0	55.5	55.3	58.8
Least depth of caudal peduncle	7.4	6.6	6.2	5.9	6.3	8.1
Snout to origin of anal fin	56.7[4]	53.7	55.2	58.8	56.1	54.0
Snout to origin of ventral fin	36.5[4]	32.5	34.2	37.5	33.8	30.4
Snout to origin of dorsal fin	44.8[4]	41.8	44.2	41.2	44.4	43.2
Height of dorsal lobe	28.3	49.5	51.7	47.9	50.7	63.5
Height of anal lobe	28.2	53.5	54.7	53.8	53.0	70.3
Length of mid-caudal rays	8.5	11.2	11.3	10.4	11.7	14.9
Length of pectoral fin	38.2	39.9	37.7	35.0	36.4	21.6
Length of ventral fin	7.0	8.5	6.7	8.4	8.3	12.1

[1] A combined count is used here since it is impossible to distinguish accurately between spines and soft rays without removing the overlying skin and scales.

[2] The row of scales which extends from the upper end of the gill cleft to the base of the caudal fin. exclusive of the small scales which cover the caudal base.

[3] Exclusive of rudiments.

[4] From Bigelow & Schroeder's figure (1929, pl. 1).

North Atlantic specimens are recorded in Table 1.

I mention the shapes of the caudal fins of these four Gulf of Mexico adults since they may be of later taxonomic interest. Two nominal species of *Taractes*, *T. brevoorti* and *T. saussuri*, are characterized by their biconcave caudal fins, *i. e.* the central rays of that fin are longer than those flanking them. In one of the four adult *Taractes* from the Gulf the central rays equal in length those on either side; in two others they are very slightly shorter, and in the fourth they are slightly longer. In none, however, is the margin of the caudal as strongly biconcave as in *T. brevoorti.*

In summary, the six western North Atlantic specimens of *Taractes* differ in the following respects: the shape of the caudal and vertical fins, form of the individual scales, presence or absence of poorly-developed lateral-line scales, shape of the eye, slight differences in body proportion, presence or absence of branching in dorsal and anal rays, and extent of the dorsal and anal fin membranes. Growth from juvenile to adult occurs in a less conservative manner in the bramids than in most acanthopterygian fishes, in which an array of distinguishing features such as these would be of considerable taxonomic and nomenclatorial interest. In the Bramidae, however, differences between individuals of different size must be evaluated with reference to the great ontogenetic changes which are known to take place.

I do not hesitate to ascribe the decrease in relative height of the dorsal and anal lobes with increasing size to normal allometric adult growth (Pl. II, Fig. 3; Barnard, 1948: 374). Similarly, all known bramid juveniles have a spine on each scale which is gradually lost with growth; it is therefore appropriate to believe that the reduction in scale armature with increase in size in our series is a function of growth. I likewise ascribe the progressive shortening of the relative height of the individual scale to normal ontogenetic change, but feel hesitant about the significance of those scales in the 74 and 349-376 mm. fish which appear to represent a lateral line. Because of the intricate pattern and bizarre form of all scales it is difficult to trace the reduction in these possible lateral-line rudiments, if such a reduction occurs. Fitch (1953: 539) reported a lateral line in his 590 mm. California *Taractes,* and Jordan's *Eumegistus illustris,* obviously closely allied to, if not congeneric with, *Taractes,* has a lateral line. The lateral line may be variable in *Taractes* and will deserve close attention when a larger series becomes available.

If this evaluation is correct, the five western North Atlantic adult *Taractes* can be referred to a single species, for the only difference which distinguishes the four Gulf of Mexico fish from the larger one from Nova Scotia is the extent of the posterior dorsal and anal fin membranes. In the fish of 618 mm. the tips of the posterior dorsal and anal rays are free from the membrane; in the Gulf of Mexico fish the tips lie within this membrane. This characteristic is among those listed by Bigelow & Schroeder (1929: 45) as diagnostic of *Taractes princeps.* I hesitate to afford it such distinction, since the only *Taractes* which possess it are the largest known individuals: Bigelow & Schroeder's of 618 mm., Johnson's types of *T. princeps* (27 to 33 inches), Fitch's California fish (590 mm.) and, if it be admitted to *Taractes,* Jordan's *Eumegistus illustris* (about 608 mm.). In fishes such as some scombrids and carangids, the dorsal and anal finlets, separate and free from a connecting membrane in the large adult, are completely or partially enclosed in a fin membrane as juveniles and young adults. Parallel fin development may occur among the bramids.

An important difference between the 74 mm. Gulf juvenile and the five adults makes its identity with them less certain. In the juvenile *Taractes* the posterior dorsal and anal rays are unbranched, although there is an indistinct line distally which separates the anterior half from the posterior. In the adults these rays are branched nearly from their bases. Since the rays of the juvenile bramids figured by Lütken (1880), Sanzo (1928) and others are similar to those of our juvenile although the adults have completely divided rays, the separation of species by this character can be questioned. However, because of this difference, the morphometric differences shown in Table 1, the great difference in size between this 74 mm. fish and the next-smallest known *Taractes* (300 mm. fork length–Barnard, 1948: 375, pl. 10), and the general confusion attending past work on the juveniles of most pelagic spiny-rayed fishes, this specimen was compared with other species closely related to it in appearance if not in phylogeny.

The scale pattern, fin structure, general physiognomy and especially the presence of distinct transverse caudal grooves distinguish our juvenile from all of the bramids other than *Taractes* to which I have compared it. *Brama raii* and *Collybus drachme* of about the same length as our fish (85 and 81 mm. in fork length respectively) are represented in the collections of Stanford University's Natural History Museum. These are totally different from the juvenile *Taractes.* Although the young of *Eumegistus illustris, T. brevoorti, T. raschi* and *T. saussuri* are unknown, none of the adults has the prominent transverse groove on the caudal peduncle, a groove which is well developed in our juvenile. The prolonged dorsal and anal fin rays, which are filamentous, with only the suggestion of branching, are reminiscent of those of the heterogeneous assemblage of species reported by Jordan (1919), but since the dorsal fin of our *Taractes* originates well behind the eye and the anal a considerable distance behind the ventral fins, I did not study in detail *Pteraclis* and the various nominal species of *Pterycombus* and *Centropholis* (Barnard, 1927: 598; Kuronuma, 1941: 56; Belloc, 1927: 239; and others). The juvenile *Taractes* is also quite distinct from the berycoid fishes which probably resemble it when young: *Trachyberyx barretoi* and *Trachichtodes spinosus.* There is little reason to believe that the 74 mm. Gulf juvenile belongs to a genus other than *Taractes.*

Taxonomic status of the western North Atlantic TARACTES.–Although most of the nomenclatorial and taxonomic difficulties which confronted Bigelow & Schroeder when they reviewed this genus in 1929 are still extant, more recent work and additional material justify a reappraisal of *Taractes* taxonomy here.

With the exclusion of *Collybus* Snyder and *Eumegistus* Jordan & Jordan, the Bramidae can be divided into the two natural groups proposed by Smitt (1892-95) and recognized by Bigelow & Schroeder (1929): those forms with more than 70 scales in a median series, *Brama,* and those with fewer than 60, *Taractes.* I am concerned here only with the few-scaled species, of which the following nominal representatives are known:

Taractes asper (Lowe, 1843)	Madeira
T. longipinnis (Lowe, 1843)	Madeira
T. brevoorti (Poey, 1861)	Cuba
T. raschi (Esmark, 1862)	Norway
T. princeps Johnson, 1863	Madeira
T. saussuri (Lunel, 1866)	Cuba
T. steindachneri (Döderlein, 1883)	Japan
T. platycephalus Matsubara, 1936	Japan
T. miltonis, Whitley, 1938	Australia

I have tentatively omitted *Eumegistus illustris* Jordan & Jordan (1922: 36) from *Taractes,* although its close resemblance cannot be ignored. Because of its lateral line and smooth-edged scales, *Eumegistus* has been considered generically distinct from *Taractes,* but I have noted above the variation in the lateral line found in specimens of *Taractes,* and both the scale spine and the notch in the rear edge of each scale in young *Brama* and *Taractes* disappear with age. Jordan & Jordan's type specimen of *E. illustris* was a large individual, about 608 mm. in length. There are, however, meristic differences between *E. illustris* and the nominal species of *Taractes.*

Fowler (1938: 44) based his description of *Brama leucotaenia* on a juvenile specimen 22.5 mm. in standard length from the Philippine Islands. Fowler compares his fish with *Brama raii* and distinguishes it from that species by the pigmentation of the dorsal fin. However, his comparison of *B. leucotaenia* with *B. raii* is of little moment since the large scales (53 in a median longitudinal series) show it to be more closely related to *Taractes.* Although I have examined Fowler's type (U.S. National Museum no. US 98817), I have not undertaken a detailed study of its relationship. Since in scale count, number of gill rakers (about 5+10) and position and extent of the lateral line it more nearly resembles *Eumegistus illustris* than any known *Taractes,* I consider this juvenile fish generically and probably specifically identical with *Eumegistus illustris.*

Collybus bears little resemblance to *Taractes* or *Brama.* More will be said of *Collybus* later.

The identity of *Taractes asper* is uncertain. Lowe's description is inadequate and the type (from Madeira) cannot be located. This fish has traditionally been considered a young stage of *T. longipinnis,* which Lowe described on the preceding page of the same paper (1843: 82). However, *T. asper* may be the young of an entirely different bramid-like fish. Mr. G. E. Maul (in correspondence) has pointed out to me the similarity between Lowe's description of *T. asper* and the berycoid species *Trachyberyx barretoi* Roule. I can contribute no original information in clarification of this question and will omit *Taractes asper* from further consideration here.

Omitting *Eumegistus, Collybus* and *T. asper,* a natural subdivision of the remaining *Taractes* species suggests itself. Gross differences in body proportions and fin structure distinguish *Taractes longipinnis* of Lowe and its allies from the type of *T. raschi,* a second specimen referred to *T. longipinnis* by Smitt *et al.* (1892-95: 80), and Matsubara's *T. platycephalus.* In body form, fin structure and scale pattern, if not in more detailed features, there is little in common between these three fishes and representatives of the *T. longipinnis* group of similar size. The type figures of *T. raschi* and *T. platycephalus* are reproduced here (Pl. II, Fig. 4; Pl. III, Fig. 5). It is unfortunate that Matsubara did not consider in more detail the resemblance between his *T. platycephalus* and Esmark's type of *T. raschi* rather than accepting Smitt's synonymy, which places *T. raschi* in the synonymy of *T. longipinnis,* and basing his comparison on Bigelow & Schroeder's paper. I have seen neither species, but if the fin structure and shape are subject to growth changes as pronounced as those in *Brama* and *T. longipinnis,* and if the vomerine dentition is as variable in *Taractes* as Lunel found it to be in *Brama,* it is difficult to characterize *T. platycephalus.*

The second subdivision of *Taractes* includes the deeper-bodied species in which both young and adults have strongly falcate dorsal and anal lobes, more steeply inclined foreheads, and distinctive squamation: *T. longipinnis* (Lowe, not of Smitt), *T. princeps, T. brevoorti, T. steindachneri, T. saussuri* and *T. miltonis.*

Döderlein's *T. steindachneri* (*in*: Steindachner & Döderlein, 1883, pl. 7) has been referred to the synonymy of *T. longipinnis* by Steindachner & Döderlein (1884: 174), a disposition accepted by Bigelow & Schroeder. It was resurrected by Jordan, Tanaka & Snyder (1913: 134), Matsubara (1936) and others on the basis of slight differences in scale and fin-ray counts. The species might better have remained in synonymy.

Taractes brevoorti and *T. saussuri* (Pl. III, Fig. 6) are alike in having a double-concave caudal fin. Although one of the Gulf of Mexico adults which I have examined has central caudal rays slightly longer than those flanking them, no recent specimens of *Taractes* approach the extreme condition shown by *T. saussuri*. These two species must be retained. *T. brevoorti* appears to be closely related to *T. longipinnis*. *T. saussuri*, on the other hand, is intermediate between *T. longipinnis* and *T. raschi* in body form and fin structure. Nothing further can be said about these species until specimens become available.

Whitley (1938: 193) distinguishes his Australian *Taractes miltonis* from the fish described by Bigelow & Schroeder (1929) as follows:

> "Head, body, scale, and fin characters agreeing excellently with the detailed description of the allied *Taractes princeps* (Johnson) recently given by Bigelow and Schroeder (Bull. Mus. Comp. Zool. Harvard, lxix., 2, February, 1929, p. 45 and plate –) but is of slightly larger size and is distinguished by having the eye-diameter about one-fourth, instead of about one-fifth the length of the head; anal lobe considerably shorter than head; comparatively longer pectoral and ventral fins; distance from ventral origin to anal origin notably less than length of head; different gill-rakers, etc."

Whitley does not describe the differences in gill rakers. The horizontal diameter of the eye of his specimen is 7.2 percent. of standard length *cf.* 5.9-6.6 in the western North Atlantic adult specimens (Table 1); the vertical diameter is 8.3 *cf.* 6.4-8.4. The head length he reported, 200 mm. or 27.8 percent. of standard length, is 2 percent. shorter than any known western North Atlantic adult. I have noted elsewhere the relative reduction in the height of the anal fin lobe with increasing length of fish in *Taractes longipinnis* and Whitley's measurement, 140 mm. or 19.5 percent. of standard length, is not out of accord with this growth change. There is no notable difference in the distance between the origins of the ventral and anal fins between Whitley's fish and Bigelow & Schroeder's (about 1 percent. of standard length), and his measurements of the lengths of the pectoral and ventral fins (35.9 and 7.65 percent. respectively) are within the range of the adult western North Atlantic material (35.0-39.9 percent. and 6.7-8.5 percent. respectively). *Taractes miltonis*, as described by Whitley, is devoid of distinguishing characteristics. This species, along with *T. steindachneri* and *T. princeps*, should go into the synonymy of *T. longipinnis*.

Taractes longipinnis and *T. princeps* were subjected to a detailed comparison by Bigelow & Schroeder (1929). These authors tentatively retained both species, listing the following combination of characters as diagnostic of *T. princeps* (p. 45):

> "1. Very deeply lunate tail.
> 2. The fact that the low rays of the anal and dorsal fins are distally free from the membrane for about a third of their length.
> 3. Great length of the anterior dorsal and anal rays.
> 4. Scales smooth, without hooks or spines (at least in adult).
> 5. Caudal pits present."

Bigelow & Schroeder's recognition of both species reflects a careful study of the problem and is the more conservative course. Since neither type is still extant, an understanding of the relationship between *Taractes longipinnis* and *T. princeps* awaits the comparison of series of specimens from the type locality, Madeira. Maul, however, who has seen many *Taractes* during his long association with the Madeiran fishery, can distinguish but one species, which he refers to *T. longipinnis* (personal communication). If it seems probable that a large series of specimens would show that the two nominal species are identical, it would be reasonable to combine the two at this time—the course recommended by those ichthyologists who have been able to examine more than one specimen. I prefer this alternative, for my material influences the interpretation of three of the distinguishing characteristics afforded *T. princeps* by Bigelow & Schroeder and the remaining two are of dubious significance in the absence of confirming material. If my 74 mm. juvenile and Barnard's 268 mm. adult are correctly referred to *Taractes*, the shape of the caudal fin changes with growth from a shallow fork to the deeply lunate form seen in the largest specimen. Similarly, there can be little doubt that the lobes of the dorsal and anal become relatively shorter during adult growth, and that there occurs a loss of scale spines and a change in the shape of the scale itself during development. Two peculiarities remain to characterize *T. princeps*: the presence of caudal pits and the absence of an interradial membrane between the posterior dorsal and anal rays. Lowe did not mention caudal grooves in his brief description of *T. longipinnis*. They may or may not have been present. As noted elsewhere, the dorsal and anal rays are free from the interradial membrane only in the largest *Taractes*, and this difference alone seems inadequate for the separation of *T. longipinnis* and *T. princeps*.

I have not attempted to review the generic nomenclature. I cannot concur in deBuen's (1935: 102) union of *Brama* and *Taractes* or with his suppression of the generic name *Brama* in favor of *Lepidotus*. *Lepidotus* Asso (1801) was used by deBuen (1935: 102), Whitley (1938: 191) and Fowler (1949: 74) in place of *Brama* (Bloch & Schneider, 1801: 98) — the needless suppression of a generic name which had been universally accepted for more than a century. The respective dates of publication, within the year 1801, have not been determined or at least were not discussed by the recent proponents of the generic name *Lepidotus*. *Taractes* is used here because it has been applied customarily to the species discussed in this paper and because there is no nomenclatorial reason for its suppression.

Since I have concluded that all of the individuals which are known from the western North Atlantic are alike and that this series possesses features which weaken the argument provided by Bigelow & Schroeder for the separation of *T. princeps* and *T. longipinnis,* I suggest that the population represented by these individuals should bear the name *Taractes longipinnis* Lowe.

I propose the following tentative synopsis of the species of *Taractes*:

I. Fewer than 50 scales in a median longitudinal series exclusive of the small scales overlying the base of the central caudal fin rays.

- A. Caudal fin "rounded." (A species of uncertain identity) . . . . *T. asper*
- AA. Caudal fin emarginate, forked or biconcave.
  - B. Standard length more than twice the greatest body depth. Pectoral fin with 17-18 rays.
    - C. Caudal fin emarginate. Forehead concave, less than an eye's diameter between upper edge of eye and dorsal profile of head.
      - D. Vomer toothed. (North Atlantic; syn.: *T. longipinnis* of Smitt, not of Lowe) . . . . *T. raschi*
      - DD. Vomer toothless. (Japan). *T. platycephalus*
    - CC. Caudal fin biconcave; tips of central rays on a line with tips of the outer caudal rays. More than an eye's diameter between eye and dorsal profile. Forehead convex. (Cuba) . . . . *T. saussuri*
  - BB. Standard length less than twice the greatest body depth. Pectoral fin with 19-21 rays.
    - E. Caudal fin emarginate. (Atlantic and Pacific; syn.: *T. steindachneri, T. princeps, T. miltonis,* not *T. longipinnis* of Smitt) . . . . *T. longipinnis*
    - EE. Caudal fin biconcave. (Cuba). *T. brevoorti*

IV. *Collybus drachme*

As well as from the type locality (Hawaii), *Collybus drachme* Snyder (1904: 525; fig. 7) has been caught off Bermuda (Kanazawa, 1952: 80). Twelve specimens have been taken in the Gulf of Mexico, all from the stomachs of yellowfin tuna and lancet fish (*Alepisaurus*) caught at the five *Oregon* stations listed earlier in this paper. They range in standard length from 33.0 to 52.5 mm. and are in various stages of digestion. A 42.5 mm. fish was cleared and stained and examined for skeletal characteristics. I have also compared the twelve specimens with Snyder's type and cotypes, which are now in the U.S. National Museum and in the Natural History Museum, Stanford University.

I use Snyder's trivial name, *drachme,* for these Gulf of Mexico specimens since I have found no significant differences between representatives from the two oceans.

The largest known *Collybus* which has been described or figured is Snyder's 81 mm. Hawaiian type. Fowler (1928: 138) reported three larger (167-186 mm.) specimens obtained in Honolulu and now in the Bishop Museum and Jordan & Jordan (1922: 35) referred to a cast of a large individual, also in the Bishop Museum. A photograph of this cast portrays a fish about 155 mm. in length, but few details of the original fish can be discerned. The physiognomy and shape and position of the fins are similar to those of *Brama* and to Snyder's larger specimens of *Collybus.* This cast was certainly not made from a *Taractes.* Some authors have suggested that *Collybus* represents the young of a species of *Brama* or *Taractes,* a view that I am reluctant to accept. The scale count separates *Collybus* from *Brama* (45-55 *cf.* 70-80 in *Brama*) and our juvenile *Taractes,* 74 mm. long, is much thicker-bodied and has more falcate fins than any *Collybus* that I have seen. *Collybus* may represent a young *T. raschi* or *Eumegistus,* but pending evidence to the contrary, *Collybus drachme* should be recognized.

The following diagnosis is a composite taken from my twelve Gulf individuals, no one of which is undamaged:

Body compressed, eliptical in outline with a ventral profile more strongly convex than the dorsal. Eye large and circular, not entering into the dorsal profile, eye diameter 2.5-2.7 in head. Mouth oblique, premaxillary extending to beneath middle of pupil. Lower jaw coterminal with upper or slightly protruding. Head 3.0-3.4 in standard length; opercular bones smooth, although the elongate scales overlying the free edges are serrated. Greatest depth of body, at origin of dorsal fin, 1.5-1.8 in standard length. Least depth of caudal peduncle 3.5-4.5 in head. Lateral line usually absent, occasionally present, complete or incomplete. Head and body lightly pigmented, a sprinkling of melanophores below orbit, along bases of all fins, on peritoneum and along dorsal edge of body.

D.: 32-34. A.: 28-29. P.: 20-21. Gill rakers: 2-3 + 8-9. Scales in a median series: 46-54; about 18 horizontal rows on body, counted obliquely upward and backward from the origin of anal fin. Vertebrae (one specimen only): 38.

Snout and forehead in front of center of eye scaleless but covered with small pores. Remainder of head and body scaled. Scales along bases of dorsal and anal fins and in axil of pectoral and ventral fins. Scales varied, those on head more strongly ctenoid than those on body. All scales vertically elongated, those on middle of body extremely attenuated, the width contained about nine times in the height. All scales with a vertical ridge and a central protruding spine or knob. About 14 keeled scales along the ventral midline between origin of pelvic fins and that of anal.

Teeth on jaws; none on vomer or palatines. Mandibular teeth in a single row posteriorly, a band anteriorly. Outermost anterior teeth recurved and enlarged. Two fangs at inner edge of anterior band at tip of mandible. Premaxillary teeth similar to those on mandible, but without anterior fangs.

Measurements, expressed as percent. of standard length: length of head, 29.9-33.9; length of snout, 5.3-7.7; length of premaxillary, 14.7-16.9; diameter of eye, 11.4-12.7. Greatest depth of body, 56.8-66.2 (decreasing with increasing length of fish), least depth of caudal peduncle, 8.3-12.7. Height of dorsal lobe, 21.1-23.9; height of anal fin, 8.4-10.4; length of pectoral fin, 27.4-32.2; length of ventral fin, 10.6-12.3.

V. SUMMARY

Except for the controversial *Steinegeria rubescens,* no species of non-pteraclid bramid fish has hitherto been reported from the Gulf of Mexico. The off-shore collections of the U.S. Fish and Wildlife Service vessel *Oregon* contain representatives of two such species, which are identified here with *Taractes longipinnis* Lowe and *Collybus drachme* Snyder. Both are described, growth changes in *Taractes longipinnis* are discussed, and the nominal species of *Taractes* are reviewed.

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EXPLANATION OF THE PLATES

Plate I

Fig. 1. *Taractes longipinnis* from *Oregon* station 1112 (Gulf of Mexico). Standard length: 357 mm. (Photograph courtesy of the Woods Hole Oceanographic Institution).

Fig. 2. *Taractes longipinnis* from *Oregon* station 1043 (Gulf of Mexico). Drawn, with some reconstruction, from a damaged juvenile 74 mm. in standard length. (Drawn by Janet Roemhild).

Plate II

Fig. 3. Profiles of five specimens of Atlantic *Taractes longipinnis*. From the smallest to the largest, the data from which these profiles were drawn were taken from (a) the 74 mm. Gulf of Mexico juvenile; (b) a South African adult of about 268 mm., from Barnard, 1948; (c) a 357 mm. Gulf of Mexico adult; (d) a 618 mm. adult from Nova Scotia, from Bigelow & Schroeder, 1929; and (e) a South African adult of about 706 mm., from Barnard, 1948.

Fig. 4. *Taractes raschi.* After Smitt *et. al.,* 1892-95, p. 80, fig. 24; from Esmark, 1862, pl. 1.

Plate III

Fig. 5. *Taractes platycephalus.* From Matsubara, 1936, p. 297, fig. 1.

Fig. 6. *Taractes saussuri.* From Lunel, 1866, pl. 2.

Fig. 7 *Collybus drachme* from *Oregon* station 1065 (Gulf of Mexico). Standard length: 33.0 mm. (Drawn by Janet Roemhild).

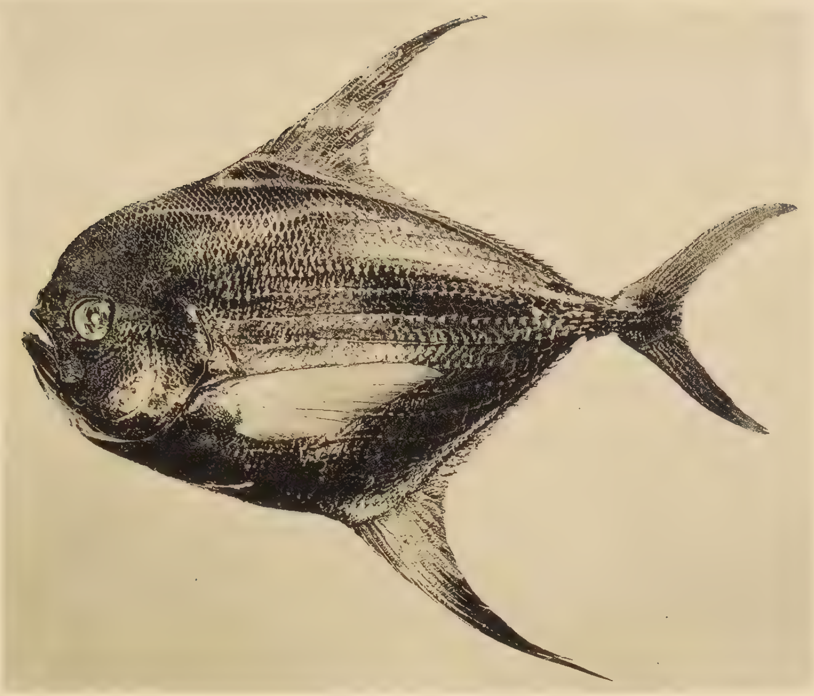

FIG. 1

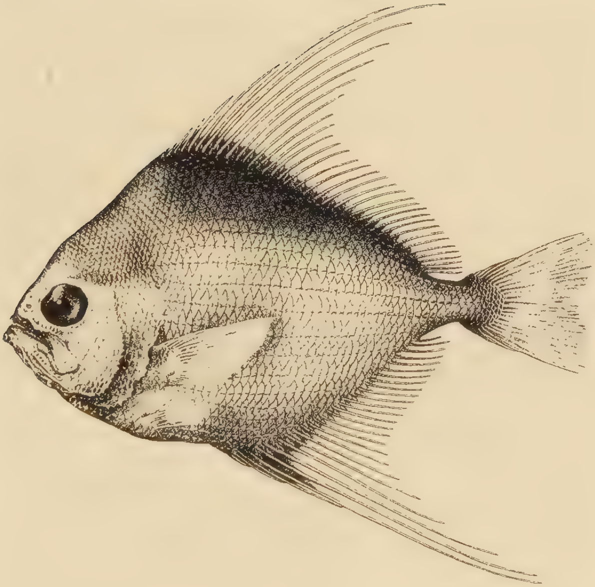

FIG. 2

ON THE BRAMID FISHES OF THE GULF OF MEXICO

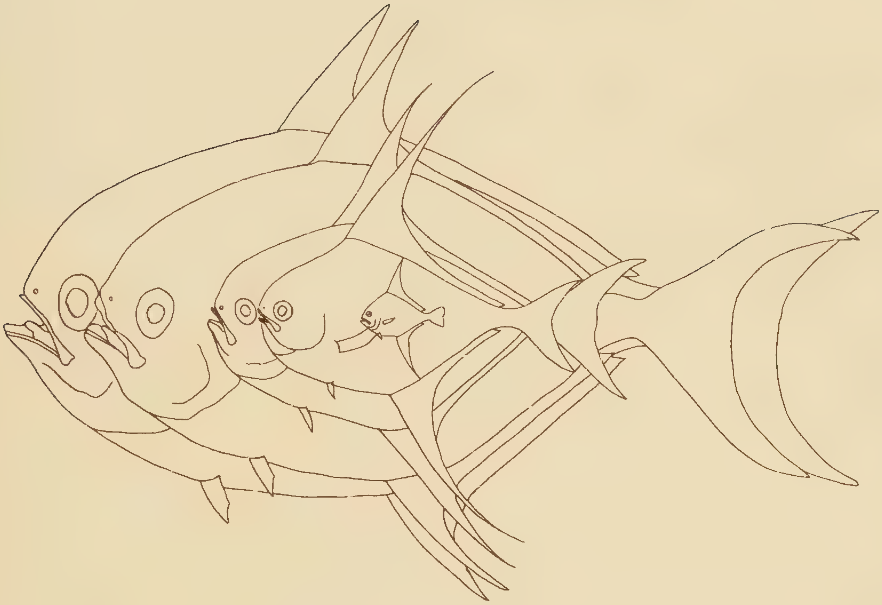

FIG. 3

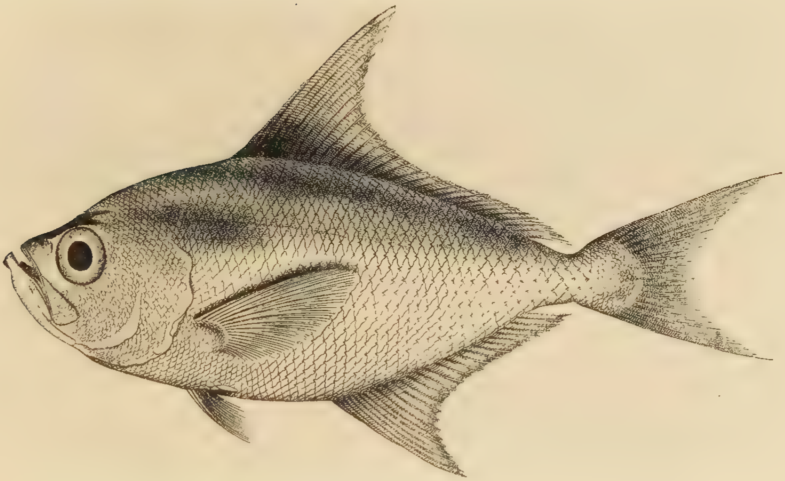

FIG. 4

ON THE BRAMID FISHES OF THE GULF OF MEXICO

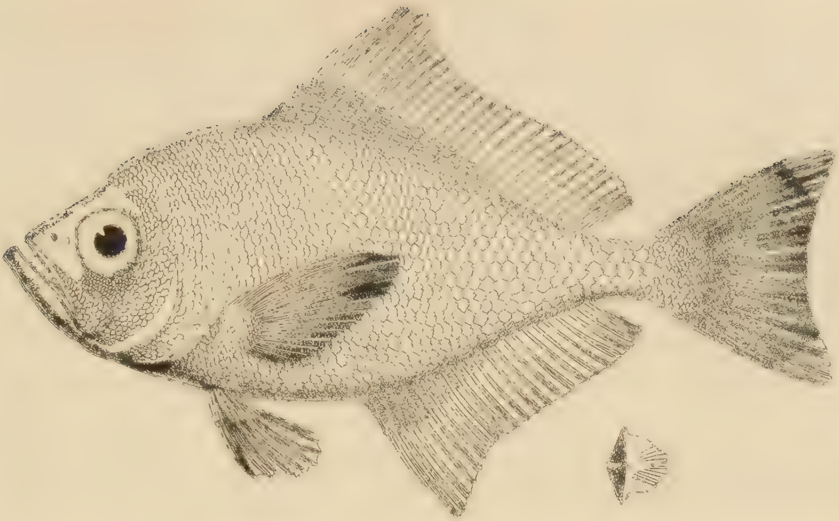

FIG. 5

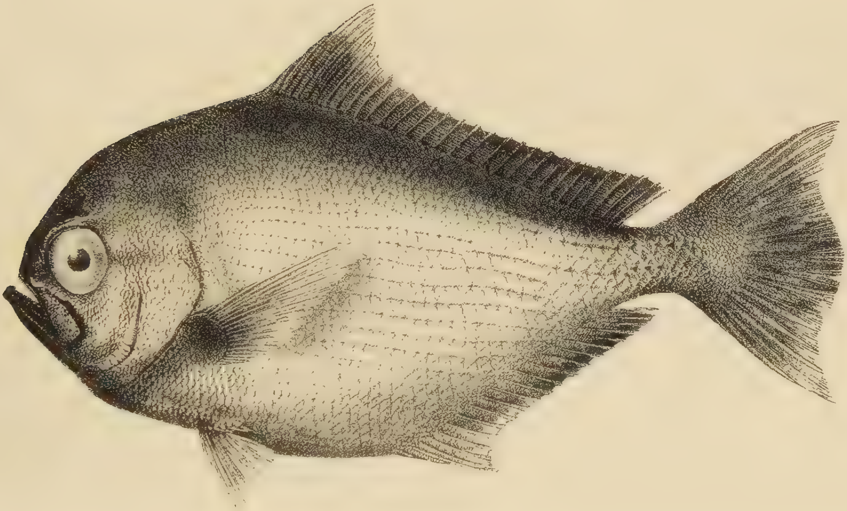

FIG. 6

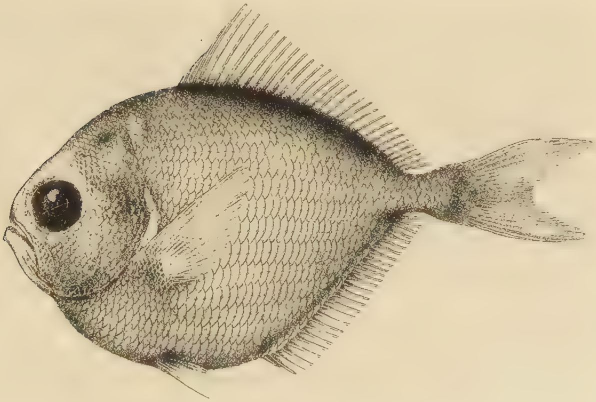

FIG. 7

ON THE BRAMID FISHES OF THE GULF OF MEXICO

RECENT CHANGES IN THE DEEP-WATER FISH POPULATIONS OF LAKE MICHIGAN

JAMES W. MOFFETT

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ABSTRACT

The deep-water fish fauna of Lake Michigan consisted of lake trout *(Salvelinus namaycush)*, burbot *(Lota lota maculosa)*, seven species of chubs or deep-water ciscoes *(Leucichthys* spp.), and the deep-water sculpin *(Myoxocephalus quadricornis)*. Other species occupied the deep-water zone but were not typically part of the fauna.

Lake trout, burbot, and a well established commercial fishery held the chub population in somewhat of a balance until the sea lamprey *(Petromyzon marinus)* destroyed the lake trout and burbot. Released from predation, one species of chub *(L. hoyi)* increased until its abundance in 1955 was 347 percent of that in 1930-1933. It is the smallest and most slowly growing of the chubs in the lake. Other chubs were reduced in abundance (1954-1955 abundance only 37 percent of that of 1930-1932) by an increased fishing pressure and by sea lamprey predation which shifted to them when lake trout and burbot became practically extinct.

Selective destruction of the large chubs reduced the average length by 1.5 and 2.2 inches in the northern and southern portions of the lake, respectively, and practically eliminated two largest species *(L. johannae* and *L. nigripinnis)*. Chubs over 10 inches long made up 72 percent of the catches in 1930-1932, but only 21.5 percent in 1954-1955.

INTRODUCTION

The deep-water (below 25 fathoms) fish community in Lake Michigan, and in the other oligotrophic Great Lakes, is comparatively simple. Until recently this community was dominated by lake trout *(Salvelinus namaycush)* and burbot *(Lota lota maculosa)* as predators with seven species of deep-water ciscoes or chubs *(Leucichthys* spp.), and the deep-water sculpin *(Myoxocephalus quadricornis)*, as prey. Since Lake Michigan became ice-free less than 11,000 years ago there has been little time for other native fish to adapt themselves to the deep-water habitat or for many exotic species to enter the drainage. Principal species inhabiting shallower areas of the lake but often mingling with deep-water species are the lake herring *(Leucichthys artedi)* suckers *(Catostomus commersoni* and *C. catostomus)*, walleyes *(Stizostedion v. vitreum)*, yellow perch *(Perca flavescens)*, and whitefish *(Coregonus clupeaformis)*. Burbot are abundant in shallow as well as deep water, and a few lake trout and chubs are commonly found in shallower areas of the lake.

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The movement of the sea lamprey into Lake Michigan and its explosive increase in abundance in the late 1940's (Applegate, 1950) added a new species that was to have a profound effect on the deep-water community. The sea lamprey spends most of its life (usually 4 or more years) in streams as a non-parasitic larva. After metamorphosis to the parasitic form it migrates to the lake, and spends 12 to 18 months feeding on fish before returning to streams to spawn and die (Fig. 1). The favored habitat during its parasitic existence is deep water and the favored food is the larger fish. This selection of larger fish probably is a matter of mechanical ease of attachment rather than preference; lampreys rapidly grow to a size at which attachment on small fish is impossible. Thus the lake trout and burbot, which had been practically free of predation, except from the fishery, were suddenly subjected to exploitation by a voracious predator. The large chubs which had grown beyond the size that could be eaten readily by lake trout and burbot were also no longer free from predation during the period when their reproductive capacity was at a maximum.

Although burbot had never been exploited heavily by man, the lake trout and chubs had long been the object of a brisk commercial fishery. The decline of the commercially exploitable lake trout under lamprey predation was easy to document (Hile, Eschmeyer, and Lunger, 1951) as was the subsequent near extinction of lake trout of all sizes (Eschmeyer, 1957). Burbot also are no longer taken in commercial nets in deep water, although they are still found in shallow-water areas. Despite the lack of supporting data, it is believed that the deep-water sculpins, free of predation by lake trout and burbot, and too small to be preyed upon by the sea lamprey have increased greatly in abundance. The chubs, however, suffered a more complex fate because they are represented by several

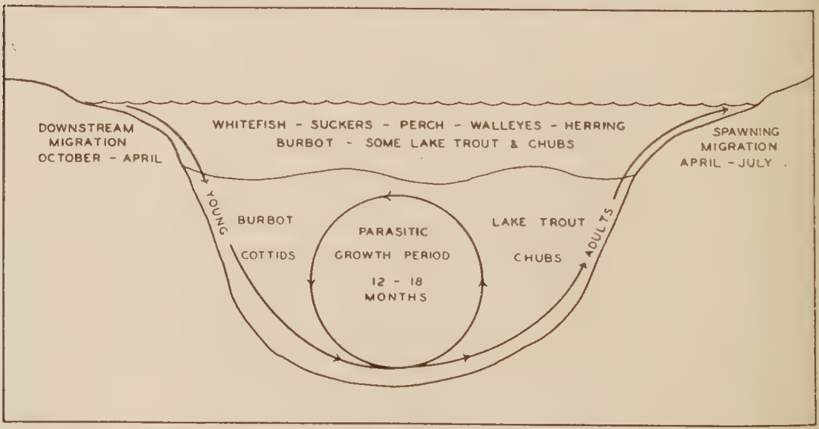

FIGURE 1.—Distribution of parasitic sea lampreys during their life in the Great Lakes contrasted to the general vertical distribution of the important species of fish.

species which when mature range from sizes too small for parasitic attachment by sea lampreys to sizes fully exploitable by the lamprey and the commercial fishery alike.

The commercial catch could not reflect accurately changes in the abundance of chubs. The disappearance of the lake trout, and the reduction in abundance of still other varieties by lamprey predation, combined to force the deep-water commercial fishermen to turn to chubs as the only plentiful fish consistently in commercial demand. Consequently, the production of chubs increased greatly as the catch of lake trout declined (Fig. 2). The abundance index derived from commercial catch reports increased slightly and fishing intensity rose sharply during this period of increasing chub production (Hile and Buettner, 1955). The increase in abundance may be only apparent, that is, largely attributable to the fishermen's keeping and marketing smaller chubs as the numbers of larger ones decreased. Previously many smaller fish were not reported in catch records because they were neither landed nor marketed. The increased catch may also be attributed in part to the transition from cotton gill nets to the use of more efficient nylon nets in recent years.

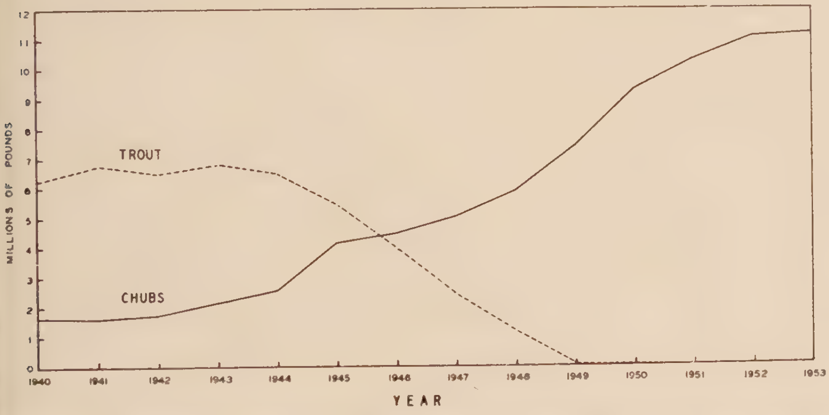

FIGURE 2.—Commercial production of lake trout and chubs in Lake Michigan showing the shift from trout to chubs as lake trout stocks declined.

I wish to acknowledge with deepest thanks the invaluable assistance of Stanford H. Smith in the preparation of this manuscript and the courtesy of John Van Oosten in authorizing my publication of summary data from the records of the 1930-1932 research from the *Fulmar*.

BIOLOGICAL CHARACTERISTICS OF LAKE MICHIGAN CHUBS

Of the eight species of *Leucichthys* in Lake Michigan, the lake herring *(L. artedi)* inhabits the shallowest water. Small numbers are taken in the deeper areas, the favored habitat of the other seven species. Thus, they are treated here as chubs although in the popular sense they are not considered as one of this group. Of the other seven species, two are relatively shallow-water forms *(L. hoyi and L. reighardi)*, three characteristically inhabit intermediate depths *(L. alpenae, L. johannae,* and *L. zenithicus)*, and two are predominantly deep-water forms *(L. kiyi* and *L. nigripinnis)*. *L. johannae* is also common in the deepest areas and all species are frequently found at depths outside their usual ranges.

The American Fisheries Society has assigned common names to the chubs but in the industry, names vary throughout the lakes and sometimes the same name may apply to different species in different lakes. Most fishermen do not recognize the full roster of species. Therefore, in sub-

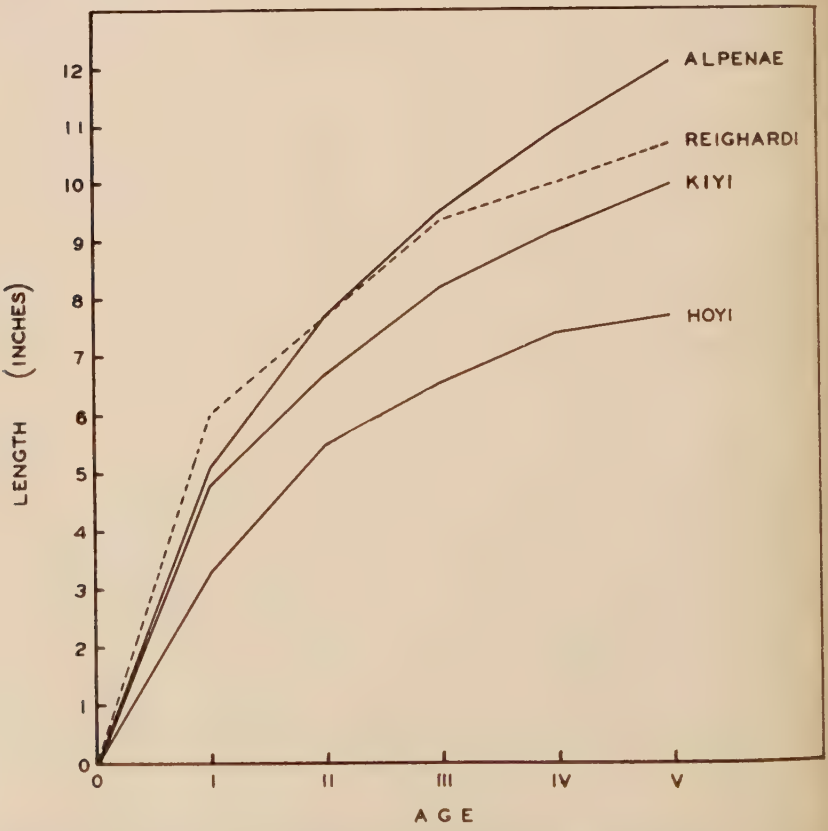

FIGURE 3.—Growth of Lake Michigan chubs (age-group V) for which life history data are available. See text for sources of data.

equent discussions the various species will be designated by their specific ame only to avoid any possibility of confusion. Some chubs could not e identified because physical differences between certain species are small nd others because they were mutilated in capture. These fish are recorded n tables as unidentified.

Growth has been studied for four species of chubs from Lake Michigan (*alpenae*, Jobes, 1949a; *hoyi*, Jobes, 1949b; *kiyi*, Deason and Hile, 1947; *eighardi*, Jobes, 1943). The growth of each of these species is different (Fig. 3). Of particular significance, as will appear in later discussions, s the extremely slow growth of *hoyi*. Of the species not shown, *johannae* nd *nigripinnis* are known from experience as the two largest chub species; *enithicus* is much like *alpenae* in size and general appearance and is probably also similar in growth; and the growth of *artedi* in Green Bay (Smith, 1956) is intermediate to that of *alpenae* and *kiyi*.

Of the four species of chubs for which biological studies have been ompleted (*alpenae*, *hoyi*, *kiyi*, and *reighardi*) all reach normal maturity n their third and fourth years of life. This age at maturity may also apply o *artedi* (as it does in Green Bay—Smith, 1956) and *zenithicus*, but it s difficult to say whether it might hold for the much larger species (*johannae* and *nigripinnis*). If it is assumed arbitrarily that chubs become usceptible to lamprey attack and use by the commercial fishery at a length of about 10 inches, it is seen that all species except *hoyi* spawn only once or twice before reaching this size (Fig. 3), but that the average *hoyi* is nearly immune from attack through its fifth year. Thus *hoyi*, free rom predation by lake trout, burbot, and lamprey, and little exploited at ts younger ages by the commercial fishery, can reproduce more efficiently han any other species of chub.

The chubs feed almost entirely on small invertebrates (mainly *Mysis* *elicta* and *Pontoporeia hoyi*). Their main competitors for this food before and during the sea lamprey invasion were cottids (deep-water sculpins) and small lake trout and burbot (Fig. 4). In turn, the small chubs and cottids were consumed by the larger lake trout and burbot while the ake trout and large chubs were cropped by the commercial fishery. The sea lamprey entered this relatively simple food chain as an additional consumer of large chubs, lake trout, and burbot. Increased cropping of hese fish lessened the competition for food between large and small chubs, and also reduced predation on small chubs and cottids. Ultimately, he lake trout and burbot were completely removed from the food chain, eliminating predation on small chubs and cottids. Furthermore, the demand of trout and burbot on the invertebrate food came to an end. Large chubs alone remained to support the sea lamprey and the commercial fishery (Fig. 4). Such a system obviously favors cottids and small chubs, particularly the slowly growing *hoyi*.

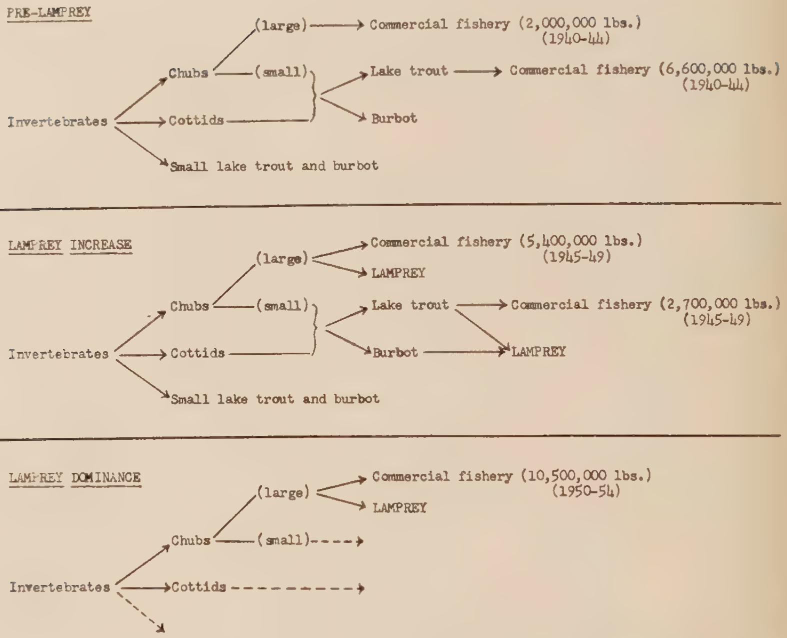
PRE-LAMPREY
(large)
Commercial fishery (2,000,000 lbs.) (1940-44)
Chubs
(small)
Lake trout
Commercial fishery (6,600,000 lbs.) (1940-44)
Invertebrates
Cottids
Burbot
Small lake trout and burbot
LAMPREY INCREASE
(large)
Commercial fishery (5,400,000 lbs.) (1945-49)
LAMPREY
Chubs
(small)
Lake trout
Commercial fishery (2,700,000 lbs.) (1945-49)
Invertebrates
Cottids
Burbot
LAMPREY
Small lake trout and burbot
LAMPREY DOMINANCE
(large)
Commercial fishery (10,500,000 lbs.) (1950-54)
LAMPREY
Chubs
(small)
Invertebrates
Cottids

FIGURE 4.—Food chains of the deep-water fish of Lake Michigan before, during, and after establishment of the sea lamprey.

CHANGES IN THE CHUB POPULATION

The first evidence of a change in the chub population of Lake Michigan came when commercial fishermen complained in the early 1950's of large numbers of bloaters (their name for all small chubs—mostly *hoyi)* in their gill nets. Measurement of these changes has been possible because the U. S. Bureau of Fisheries research vessel *Fulmar* conducted studies in Lake Michigan in 1930-1932 (long before the sea lamprey invasion) during which extensive gill-net fishing was conducted and data were compiled on the size, abundance, distribution, and other characteristics of the various species of chubs. To obtain comparable records, the research vessel *Cisco* operated by the U. S. Fish and Wildlife Service fished gill nets of identical specifications during 1954-1955 at the same depths, locations (Fig. 5), and periods of the year as the *Fulmar.* Although analysis of the 1954-1955 data is not yet complete, the findings on abundance, species composition, and size are given here.

In 1930 and 1931 the *Fulmar* operated almost exclusively in the south and central portions of Lake Michigan and in 1932 it worked in the northern end (for details see Deason, 1932). The *Cisco* operated in the area from Manitowoc and Ludington south in 1954, and from these ports

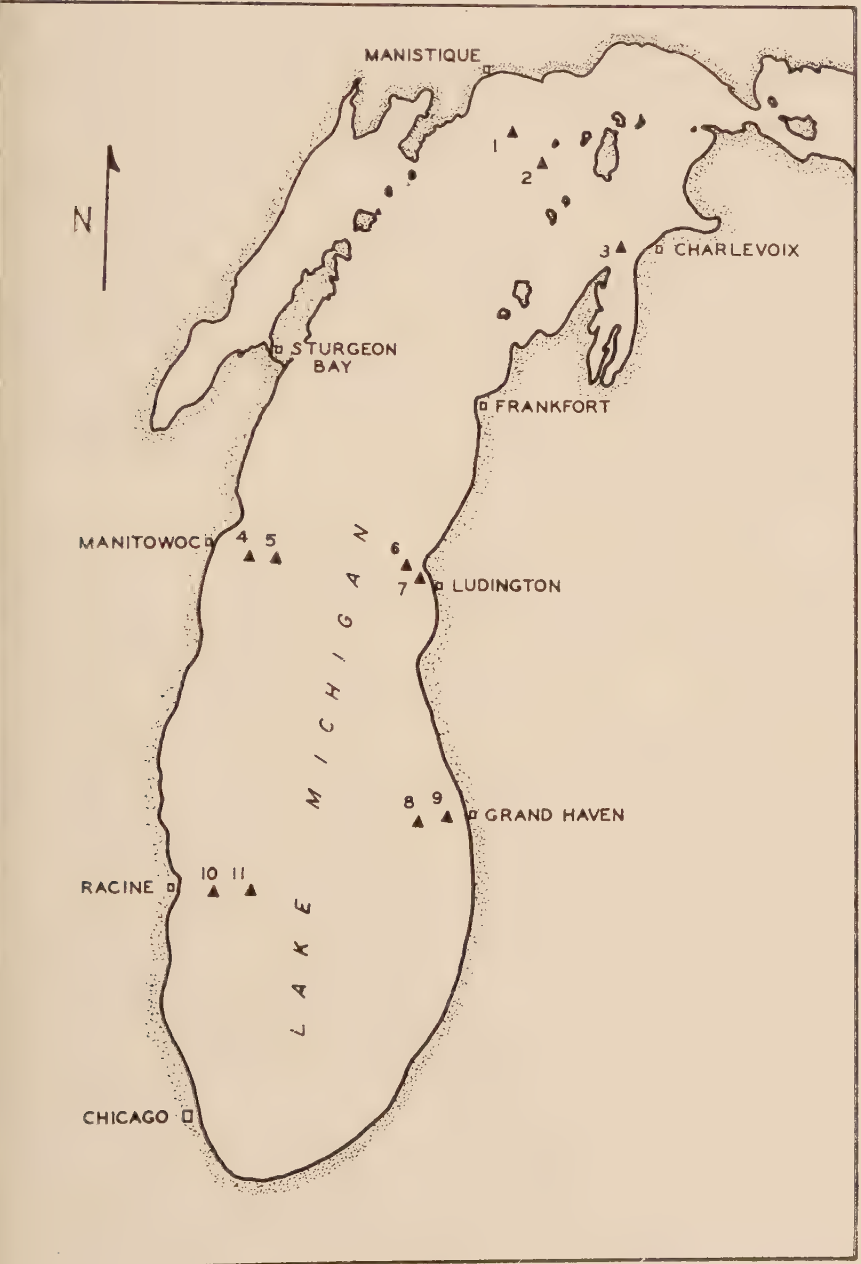

FIGURE 5.—Locations of gill-net stations in Lake Michigan where identical nets were set by the *Fulmar* in 1930-1932 and the *Cisco* in 1954-1955.

north in 1955. Standard gangs of gill nets used for comparisons between the two periods were made of linen. Each gang contained one net each of the following mesh sizes (stretched measure as manufactured): 2⅜, 2½, 2⅝, 2¾, and 3 inches. Each net was 510 feet long and 5 feet deep. In actual practice various lengths of each mesh were fished depending on the amount of serviceable gear on hand, but results for analysis have been adjusted to represent the catch of a standard gang. In the *Fulmar* operations in northern Lake Michigan during 1932, the largest (3-inch) and smallest (2⅜-inch) mesh sizes were not fished. In the *Cisco* studies, however, all meshes were fished at each station.

The combination of data from various depths, locations, and times of the year in this presentation disregards the known variations of size, abundance, and species composition with depth, location, and time. These combinations were made only after examination of detailed data revealed that no erroneous general conclusions would result. In all situations the changes from 1930-1932 to 1954-1955 were so large as to be clearly evident despite the combination.

Abundance of Chubs

The abundance (number of fish per standard gang) of *hoyi* (the smallest chub) increased greatly between 1932 and 1954 (Table 1), before and after the sea lamprey became established.[1] Among the larger species, *artedi* remained the same or increased slightly in all areas and *kiyi* remained the same off the east shore of southern Lake Michigan, but in all other areas chubs, except *hoyi*, were far less plentiful in the later period. In fact, the two largest species *(johannae and nigripinnis)* were absent from the 1954-1955 catches. A few *nigripinnis* (17 fish) were taken in nylon nets that were fished to obtain biological and distributional data on the chubs but no *johannae* were taken during the entire study even though nets were specifically set in areas where they previously had been abundant. The last positive record of *johannae* in Lake Michigan was made in June 1951 when Stanford H. Smith identified several specimens in the catch of commercial nets set at 100 fathoms in Grand Traverse Bay.

The abundance figures (Table 1) clearly demonstrate that the expected results of the addition of the sea lamprey to the deep-water food chain (Fig. 4) actually have come about. The smallest chub *(hoyi)*, relieved of predation and strong competition for food, has increased greatly in numbers. The previously abundant medium-sized chubs *(alpenae, kiyi, reighardi,* and *zenithicus)* have decreased sharply, and the largest species *(johannae* and *nigripinnis)* have suffered the same fate as the large lake trout and burbot—near-extinction. *Artedi* which occurs in abundance in shallow areas of the lake is almost free of lamprey predation and has

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[1] Summary tables of abundance and length composition of chubs in 1930-1932 were supplied by Dr. John Van Oosten, U. S. Fish and Wildlife Service who directed the operations of the *Fulmar*.

TABLE 1.—*Number of chubs taken in Lake Michigan from gill nets of identical specifications fished at the same depths, locations, and time of the year in 1930-1932 and 1954-1955.*

[Expressed as catch per 1,530-foot gang with equal amounts of 2½-, 2⅝-, and 2¾-inch mesh in the north end and as catch per 2,550-foot gang with equal amounts of 2⅜-, 2½-, 2⅝-, 2¾-, and 3-inch mesh in south end]

Species	North end[1]		South end			
			West shore[2]		East shore[3]	
	1932	1955	1930-1931	1954-1955	1930-1931	1954-1955
L. alpenae	24.3	0.8	12.5	6.5	65.3	24.6
L. artedi	0.6	0.7	0.8	1.9	2.5	2.9
L. hoyi	26.8	54.4	49.0	122.7	138.7	495.5
L. johannae	0.4	0	2.3	0	13.1	0
L. kiyi	6.6	3.8	39.8	7.6	41.2	44.3
L. nigripinnis	0.3	0	1.2	0	2.7	0
L. reighardi	12.0	6.5	24.4	6.9	136.8	18.2
L. zenithicus	9.7	1.0	14.1	12.7	20.5	12.1
Unidentified	4.2	0.2	12.9	3.1	17.1	8.3
Total	84.9	67.4	157.0	161.4	437.9	605.9
Number of gangs	58	20	26	18.5	32	30
Average nights fished	6.2	3.7	12.4	4.0	10.6	4.0

[1] Nets set at 50 fathoms off Manistique and Charlevoix and southwest of Beaver Island.

[2] Nets set at 30 and 70 fathoms in the vicinity of Manitowoc and at 25 and 50 fathoms near Racine.

[3] Nets set at 25 and 60 fathoms in the vicinity of Ludington and at 25 and 50 fathoms off Grand Haven.

been more than able to maintain its small numbers in the deep-water community.

Although the species composition of chubs has been modified greatly, the total abundance has not undergone a drastic change (Table 1; Fig. 6). Furthermore, the greater abundance of chubs on the east than on the west shore of central and southern Lake Michigan that existed in 1930-1932 (see Van Oosten, 1933, and papers by Jobes) was still evident in 1954-1955. Thus whatever factor or factors that regulate the availability of fish on the two shores have not been changed by modification of the fish populations.

The change in abundance of *hoyi* in 1954-1955 varied greatly in different sections and depths of the lake (Table 2). Only at Charlevoix was *hoyi* less abundant (index value, 88 percent) than it had been in 1932. Earlier studies showed that *hoyi* in the northern sections of the lake were 2.3 to 2.7 inches longer, on the average, than in other sections (Jobes, 1949b). Thus they would be more vulnerable to attack by the sea lamprey and capture by the commercial fishery. In other regions of Lake Michigan *hoyi* had increased to 111 to 1,136 percent of its 1930-1932 abundance. The average index value was 347 percent for all locations (Table 2). The percentages of the other species varied irregularly from area to area

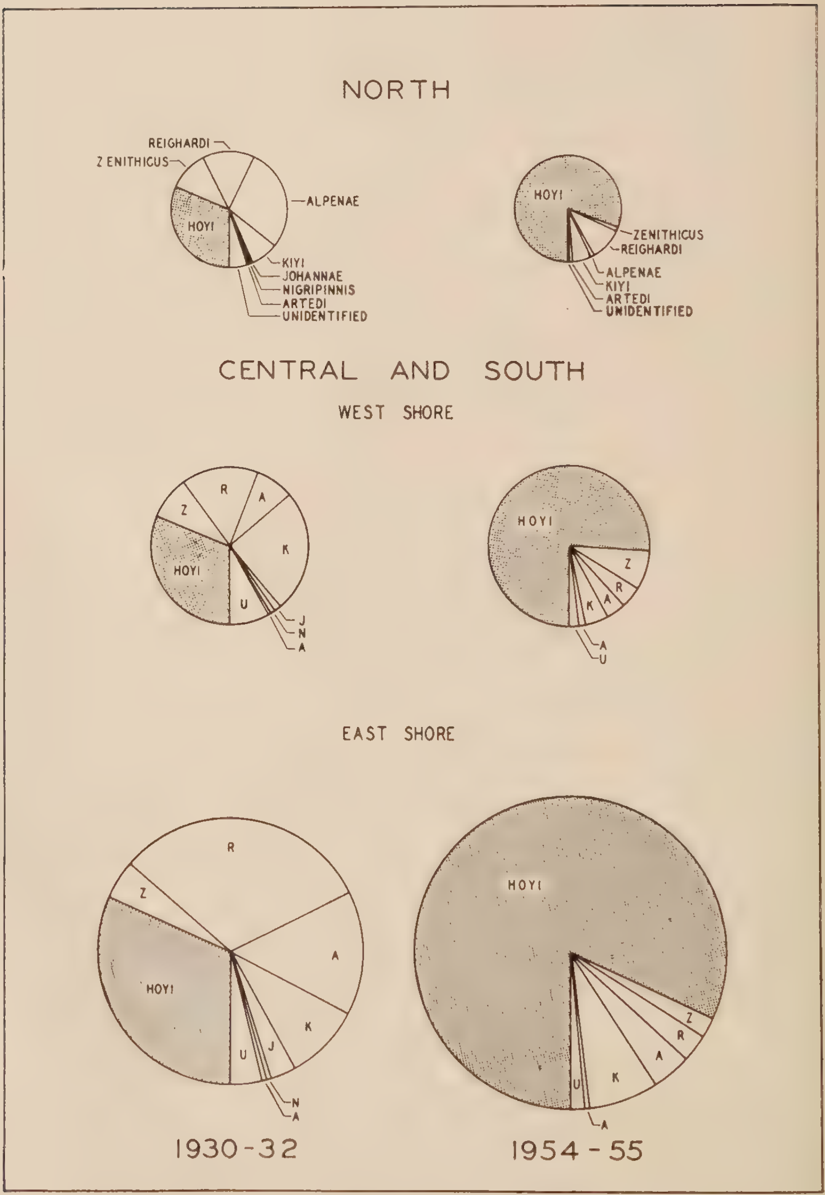

FIGURE 6.—Abundance and species composition of chubs in 1930-1932 and 1954-1955, in different areas of Lake Michigan. Area indicates relative abundance; see Table 1 for numerical values.

because small numbers of each were taken in many localities. Data for other species have, therefore, been combined (Table 2). In all locations the abundance of chubs other than *hoyi* has decreased. This segment of the population ranged from 13 to 73 percent of its 1930-1932 level and averaged 37 percent—a net decrease in abundance of 63 percent.

LENGTH COMPOSITION OF THE CHUB POPULATION

A selective destruction of large chubs that was strong enough to change radically the species composition of the population should be expected also to modify the length composition of the stock. In fact, the greater abundance of the small, slowly growing *hoyi* has already dictated that such a change must occur.

Chubs are characteristically larger in the northern end of Lake Michigan than in the remainder of the lake and must, therefore, be treated separately

TABLE 2.—*Changes in availability of different segments of the chub population of Lake Michigan from 1930-1932 to 1950.*

[Numbers of chubs per gang of gill nets in 1954-1955, expressed as percentages of the catch in the same gear in 1930-1932. Number of fish per standard gang 1930-1932 and 1954-1955 respectively in parentheses.]

Location	Depth (fathoms)	1954-1955 catch as percentage of 1930-1932 catch	
		Leucichthys hoyi	Other species[1]
North			
Manistique	50	420 (14.7-61.7)	23 (55.9-13.1)
Island area	50	236 (29.7-70.1)	30 (62.3-18.6)
Charlevoix	50	88 (36.0-31.5)	13 (56.2-7.2)
Central			
Manitowoc	30	111 (69.8-77.8)	55 (47.8-26.2)
Manitowoc	70	389 (8.7-33.8)	15 (188.6-28.9)
Ludington	25	331 (111.5-369.6)	14 (270.0-37.5)
Ludington	60	1,136 (58.2-661.3)	73 (162.8-119.4)
South			
Racine	25	299 (70.1-209.3)	32 (103.4-32.7)
Racine	50	357 (47.3-169.0)	73 (92.4-67.7)
Grand Haven	25	286 (262.6-751.9)	28 (500.2-138.0)
Grand Haven	50	163 (122.3-199.4)	56 (263.8-146.5)
Average		347	37

[1] Includes unidentified chubs.

in considerations of length composition. In fact, chubs in the north averaged 1.3 inches longer than in central and southern Lake Michigan in 1930-1932 (Table 3). This difference was reduced to 0.6 inch in 1954-1955, due to the greater selective destruction of large fish in the north, where more large fish occurred.

Changes of length were large in each area. Chubs that averaged 11.4 inches in the northern portion of the lake in 1932 were only 9.2 inches in 1955—a decrease of 2.2 inches. In the central and southern portion the chubs averaged 10.1 inches in 1930-1931 and 8.6 inches in 1954-1955, a decrease of 1.5 inches. The change in the lengths of the chub catch is shown more clearly by the length-frequency distribution (Table 3; Fig. 7). The shorter groups that were sparsely represented in the catch during the early 1930's have become the dominant length groups in the recent catches. The shift to shorter length is not entirely due to the greater abundance of the small *hoyi* and lesser abundance of larger species. Pre-

TABLE 3.—*Length distribution of chubs of different sections of Lake Michigan in 1930-1932 and 1954-1955.*

[Fish were taken in experimental gill nets of identical specifications fished at the same depths, locations, and times of the year in 1930-1932 and 1954-1955. Frequencies are expressed as percentage of fish in each length group. Fish from 2½, 2⅝-, and 2¾-inch mesh combined]

Total length (inches)	North		Central and South	
	1932	1955	1930-1931	1954-1955
5.5- 5.9	>0.1	..	..	0.3
6.0- 6.4	..	..	0.4	1.0
6.5- 6.9	..	0.4	1.8	4.2
7.0- 7.4	≥0.1	1.3	6.9	14.1
7.5- 7.9	0.4	8.3	7.0	17.5
8.0- 8.4	1.0	15.3	4.6	12.9
8.5- 8.9	1.2	17.2	4.3	11.4
9.0- 9.4	1.7	15.1	4.4	9.6
9.5- 9.9	2.5	15.1	6.5	9.8
10.0-10.4	9.0	16.2	14.5	8.5
10.5-10.9	21.4	7.4	17.3	6.1
11.0-11.4	20.2	2.8	15.1	2.8
11.5-11.9	14.1	0.9	9.0	1.1
12.0-12.4	10.3	0.2	5.1	0.4
12.5-12.9	8.5	0.1	1.6	0.2
13.0-13.4	4.4	..	0.5	0.1
13.5-13.9	2.4	..	0.4	..
14.0-14.4	1.3	..	0.2	..
14.5-14.9	0.6	..	0.1	..
15.0-15.4	0.3	..	>0.1	..
15.5-15.9	0.3	..	0.1	..
16.0-16.4	0.2	..	..	..
16.5-16.9	≥0.1	..	0.1	..
17.0-17.4	0.1	..	>0.1	..
18.5-18.9	>0.1	..	..	..
Average length..........	11.4	9.2	10.1	8.6

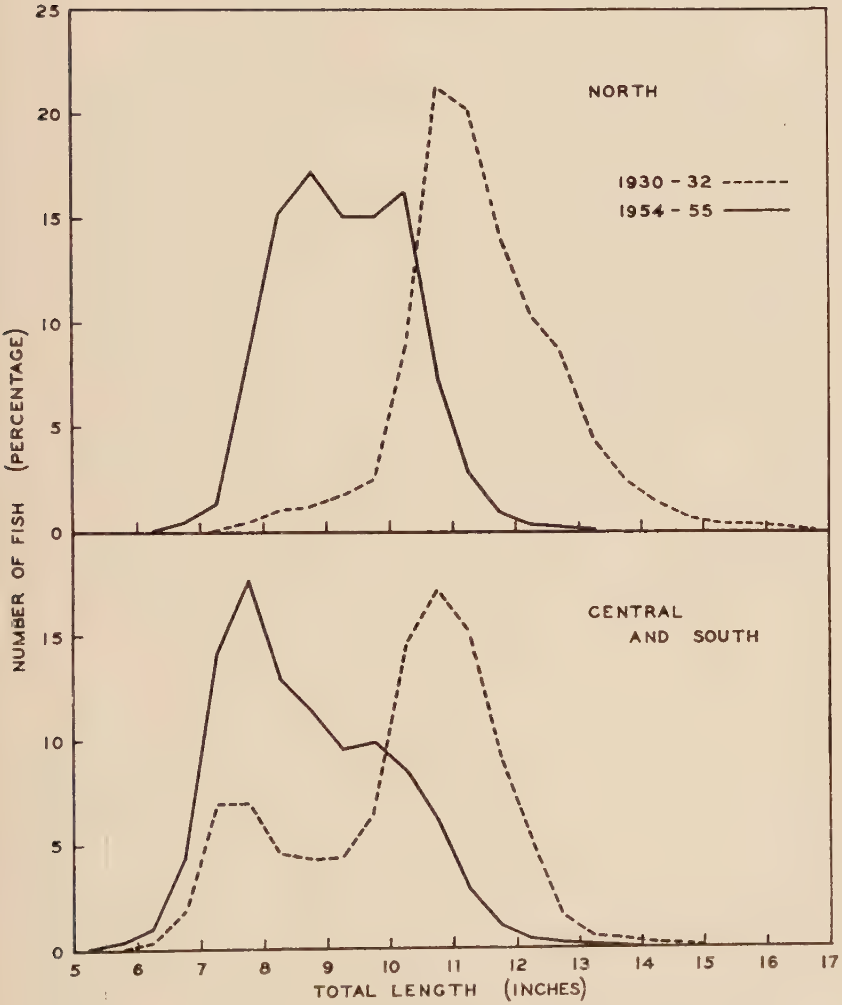

FIGURE 7.—Length distribution of chubs of Lake Michigan caught in identical gear before and after the sea lamprey became established.

liminary examination of the length distribution of the individual species shows a pronounced decline in length for each.

EFFECT OF CHANGES IN THE CHUB POPULATION ON THE COMMERCIAL FISHERY

An historical review of the chub fishery clearly indicates a long-term reduction in the size of fish in the chub population in Lake Michigan (Hile and Buettner, 1955). The two largest species, *johannae* and *nigripinnis,* almost extinct now, were major contributors to the chub catch prior to the turn of the century but were only lightly represented in 1930-1932 (Table 1.) At this same period the medium-sized species *(alpenae, kiyi, reighardi, zenithicus)* were abundant and in high demand. Although its larger individuals have contributed significantly to the catch, *hoyi* has always been considered a nuisance by the commercial fishermen who have avoided it wherever possible by not fishing in areas where it is abundant, and by hanging their gill nets "tight" so that bloaters (all small chubs but mostly *hoyi)* are less likely to be caught.

In recent years when the chub fishery of Lake Michigan has reached its greatest intensity (Hile and Buettner, 1955), *hoyi* is the only generally abundant species. The abundance of medium-sized fish is variable in local areas. Thus, for some fishermen the recent conditions have not been as

TABLE 4.—*Percentage of chubs shorter than 10 inches and 10 inches and longer taken from Lake Michigan in experimental gill nets of identical specifications in 1930-1932 and 1954-1955.*

[Figures represent all fish taken from a gill net with equal amounts of 2½-, 2⅝-, and 2¾-inch mesh]

Location	Depth (fathoms)	Percentage of chubs			
		Shorter than 10 inches		10 inches and longer	
		1930-1932	1954-1955	1930-1932	1954-1955
North					
Manistique	50	8.6	79.2	91.4	20.8
Island area	50	4.3	65.1	95.7	34.9
Charlevoix	50	7.7	73.0	92.3	27.0
Central					
Manitowoc	30	56.3	70.8	43.7	29.2
Manitowoc	70	27.6	73.7	72.4	26.3
Ludington	25	39.7	83.6	60.3	16.4
Ludington	60	34.3	82.7	65.7	17.3
South					
Racine	25	34.8	76.9	65.2	23.1
Racine	50	55.2	96.8	44.8	3.2
Grand Haven	25	21.1	85.8	78.9	14.2
Grand Haven	50	18.5	75.9	81.5	24.1
Average		28.0	78.5	72.0	21.5

acute as they have been for others. Still *hoyi* is more important in supporting the fishery in all areas than it has ever been. In many sections commercial fishermen are forced to fish for and market at low prices these small chubs that were previously discarded. Some fishermen, when faced with this prospect, have gone out of business.

Although *hoyi* is generally considered undesirable on the market because of the thinness of its meaty portions, size remains the primary criterion in determining the marketability of chubs. The size of each species has declined; thus, the size of individuals in, rather than the species composition of, the population determines the former and recent potential contribution to the commercial fishery. If it is assumed arbitrarily that chubs 10 inches and longer have consistent market demand, 72.0 percent of the chubs taken in mesh sizes most commonly used in the chub fishery (2½, 2⅝, and 2¾ inches) were marketable in 1930-1932 (Table 4). In 1954-1955, however, only 21.5 percent of the chubs taken in nets of the same mesh sizes were marketable. The change was most pronounced in the northern portion of the lake where previously over 90 percent of the chubs exceeded a length of 10 inches and more recently 34.9 to 20.8 percent were marketable. Hardest hit, however, are some areas in the southern portion of the lake where as little as 14.2 to 3.2 percent of the recent catch has been of marketable size.

Data from the 1930-1932 study show that the average length of *hoyi* taken in gill nets increases as the mesh size decreases (Jobes, 1949b). This

TABLE 5.—*Average length of chubs taken in Lake Michigan in experimental gill nets of identical specifications in 1930-1932 and 1954-1955.*

Location	Depth (fathoms)	Average total length (inches) of chubs caught in			
		2⅜-inch mesh		2½-, 2⅝-, 2¾-inch mesh	
		1930-1931	1954-1955	1930-1932	1954-1955
North					
Manistique	50	..	9.5	11.2	9.1
Island area	50	..	9.7	11.6	9.4
Charlevoix	50	..	9.8	11.4	9.2
Central					
Manitowoc	30	10.1	9.6	9.4	9.0
Manitowoc	70	10.1	9.7	10.3	9.0
Ludington	25	10.2	9.5	9.9	8.6
Ludington	60	10.1	9.3	10.1	8.9
South					
Racine	25	10.3	9.3	10.0	8.8
Racine	50	..	..	9.5	7.6
Grand Haven	25	10.4	9.4	10.5	8.5
Grand Haven	50	10.1	9.2	10.7	8.7
Average					
All data		10.2	9.5	10.4	8.8
Central and south		10.2	9.4	10.1	8.6

peculiar relation holds true because the smallest mesh size used in these studies (2⅜ inches) approaches the size at which *hoyi* is most effectively gilled. Most *hoyi* pass through larger mesh sizes; therefore, as the mesh size increases a higher percentage of these fish are caught by entangling their loose and rather extended mouth parts in the net. In a population dominated by *hoyi* it should be expected that a smaller mesh size should produce a larger fish. Even in 1930-1932, when *hoyi* was abundant but did not dominate the population, the average size of chubs taken in commercial meshes (2½ to 2¾ inches) in the southern section of the lake (where all meshes were fished in both periods) was 0.1 inch smaller than those taken in the 2⅜-inch mesh (Table 5). The greater difference of 0.8 inch occurred in the same area of the lake, however, when *hoyi* dominated the population in 1954-1955. Thus if the chub fishery should at some time become predominately dependent on *hoyi* for support, a mesh size smaller than the current 2½-inch minimum should be considered.

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Spectral Reflectance Applied to the Study of Heme Pigments

It is a common practice to make qualitative and rough quantitative estimates of the content of pigmented substances in materials by the intensity and spectral distribution of color. It is rather surprising, then, that more use has not been made of spectral reflectance in qualitative and quantitative analytic chemistry. It is the intention of this report (*1*) to point out the potentialities of the method, particularly in biochemical analysis, and to illustrate its application in the investigation of certain heme pigments.

The use of spectral reflectance curves n the specification of color by the physicist is well known. Lermond and Rogers (*2*) have recently pointed out the possible wider utility of spectral reflectance measurements in chemical analysis and have reviewed the limited amount of work in this field. Applications in biochemistry seem to be particularly rare.

In the course of research on pigment systems in fish flesh, we investigated the use of spectral reflection measurements. A standard reflection attachment to the Beckman DU spectrophotometer was used. Samples, either 90-mesh, nonabsorbing powders with absorbing solutions or solids added, or tissue forced through a 16-mesh, stainless-steel screen, were packed into 1¼ by 1/16-in. aluminum planchets and covered with glass plates. Comparison was made with a standard consisting of the nonabsorbing diluent powder or with a disk of high-fired alumina.

Adherence to Beer's law was tested by adding different amounts of standard copper sulfate solution to the crystalline alumina diluent and measuring the absorbancy at 620-mμ wavelength. The law seems to be applicable at this wavelength and for the range of concentrations indicated (Fig. 1). These results are at variance with those that Winslow and Liebhafsky (*3*) reported for reflectance from known concentrations of metals spot-tested on paper. The discrepancy may be due to the difference in the thickness of the supporting media for the samples used in the two experimental situations. Measurements were attempted with whole blood dispersed on 90-mesh crystalline alumina. In this case, adherence to Beer's law was found t low concentrations, but oxidative anges caused deviation in the higher nge.

In transparent, internally absorbing systems (dielectrics), it can be assumed that reflection takes place at phase interfaces and by diffuse scattering from large molecules. Adherence to Beer's law would signify that, for systems of similar opacity, the average path length of the incident and emergent beam is the same and would also justify the use of absorbancy (optical density) in the plotting of spectral reflectance data. Thus spectral reflectance can presumably be used for the comparative quantitative analysis of stable systems of dielectric materials of similar general composition. Such measurements have been applied in the present work.

The use of the method for the characterization of pigments by their reflectance curves is illustrated in Fig. 2. Various derivatives of respiratory pigments can be identified in the reflection spectra of tuna flesh that is exposed to a variety of oxidative environments. An advantage afforded by this technique is the possibility of evaluating the spectral absorbance of opaque concentrated systems without recourse to the special cells, or to dilution in solution with its attendant possibility of alterations, that are employed in transmission methods. For example, the spectrum of whole human blood can be directly determined using an inert crystalline alumina diluent (Fig. 2*c*).

Spectral reflectance is particularly suited to *in situ* studies on pigment systems where extractive procedures are difficult or impossible or where such procedures would cause undesirable changes. It is characteristically a simple technique in that a minimum of preparative and extractive operations is involved. Specifically, absorbance studies on coagulated proteins were possible; in addition, the examination of residues after the extraction of certain components gave a more complete picture of extraction efficiency and relative solubilities. Furthermore, one is able to follow the course of induced or natural chemical reactions in such systems. For the heme protein systems studied, the wavelengths of absorption maxima in reflection corresponded exactly to those found in transmission, and complete interchangeability of data was noted. Thus the large amount of data accrued from measurements in transmission would be available to workers in the field of reflectance in systems where this interrelationship is found to be true.

The measurement of spectral reflectance offers a method for the study of dielectric materials that absorb and reflect internally, as opposed to surface reflectors such as metals. It is felt that this investigative tool merits the further attention of the biological and analytic worker.

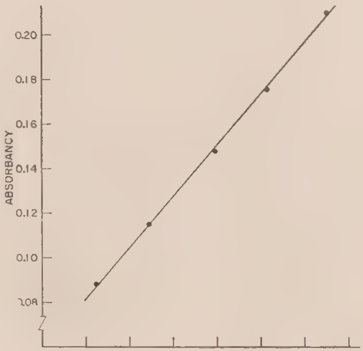

Fig. 1. Beer's law plot for copper on 90-mesh crystalline alumina.

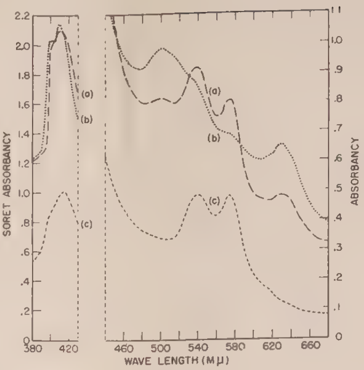

Fig. 2. Spectral reflectance curves *a*, mixed oxymyoglobin and metmyoglobin in tuna flesh; *b*, metmyoglobin in tuna flesh; *c*, oxyhemoglobin in whole blood.

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References and Notes

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A SIX-YEAR STUDY OF THE SURVIVAL AND VITALITY OF HATCHERY-REARED RAINBOW TROUT OF CATCHABLE SIZE IN CONVICT CREEK, CALIFORNIA[1]

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INTRODUCTION

The survival and physical vitality of hatchery-reared trout in streams are matters of serious concern to fish culturists, fishery managers, and a constantly increasing multitude of fishermen. Fish culturists and fishery managers have the responsibility of maintaining or improving trout fisheries, and in order to do so they must rely on hatchery-reared trout to supplement natural production in many lakes and streams. During the last decade, emphasis on stocking has shifted from trout of fry and fingerling size to those of legal or catchable size, causing fish-cultural activity to mushroom to meet an ever increasing demand. Concomitant with this change there have been numerous investigations designed to evaluate the success of stocking trout of catchable size, and interpretation of results ranges from extreme pessimism to guarded optimism. Literature on the subject has been reviewed by Schuck (1948), Smith (1948), Miller (1949), Wood (1953), and by the Wisconsin Department of Conservation (1953), and need not be repeated here. However, it is pertinent to list certain general conclusions that have been drawn from the investigations concerned with the survival of legal or catchable-size, hatchery-reared trout in streams.

1. Greatest returns to the creel may be expected from plantings made immediately prior to and during the open season in areas of heavy angling pressure.
2. If the trout so stocked are not caught within 2 to 4 weeks after release, most of them are no longer available to the angler and are presumed to have died.
3. Mortality in trout streams is high and affects wild as well as hatchery fish, but is significantly higher among the hatchery trout. Overwinter survival of hatchery trout is particularly low, often nil.
4. Failure of hatchery trout to survive is attributed to inability to compete with wild trout; to absence of natural selection during early life stages in the hatchery; to abnormal physical condition due to fish-cultural techniques; and, to stocking practices and methods.

Most of the investigations are based on the return of marked hatchery trout to the angler's creel and on population estimates made at various times through the year, usually by means of one of several electro-shocking techniques. Shortcomings are evident in some of the conclusions drawn from these procedures: (1) failure of anglers to catch the trout is interpreted to mean that the planted fish died and hence were not available; (2) population estimates made in or near the sites of liberation do not necessarily take into account the mobility of trout; and, (3) the adequacy of certain population sampling procedures, especially in larger streams, is doubtful.

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[1] Submitted for publication August, 1956.

Schuck (1948) and Adelman and Bingham (1955), cognizant of these and other deficiencies relative to the appraisal of survival and physical vitality of hatchery-reared trout in natural streams, stressed the importance of controlled survival experiments. Emphasis was placed on confining the test fish in limited areas where escapement could be prevented by means of screens and where the numbers of test fish could be accurately known. The importance of comparing wild and hatchery-reared trout of the same size, in the same stream, and over the same span of time was also emphasized.

The above qualifications for experimental procedure were fulfilled at Convict Creek Station. This report presents the results of six years of controlled, yearlong survival experiments using catchable-size,[2] hatchery-reared rainbow trout and resident brown trout of comparable size.

The program was conducted in cooperation with the Inland Fisheries Branch of the California Department of Fish and Game.

THE EXPERIMENTAL STREAM

To test the ability of hatchery-reared trout to survive in streams under controlled natural conditions, Convict Creek Experimental Stream was established in 1936 by the United States Bureau of Fisheries (predecessor agency of the Fish and Wildlife Service) in cooperation with the California Division of Fish and Game (now the California Department of Fish and Game) and the United States Forest Service.

The facilities of the experimental stream and the objectives of the program were described by Needham and Rayner (1939). It should be noted that these experiments were the first of their kind in the country. Effort was concentrated on the study of survival of stream-stocked, hatchery-reared fry and fingerling trout. The program was designed to test the stocking tables developed by Embody (1927) and Davis (1938), and to devise stocking policies based on the results of the new experiments. The experimental stream facilities consisted of five small side channels that were supplied with water by diversion from the main stream. These channels had a total length of 4,200 feet and each was divided into 100- to 400-foot sections by means of concrete flumes keyed for screens and flashboards. Work was limited to 3 to 5 months during the summer season and was terminated in 1943 because of World War II. Results of five years' work, from 1938 to 1942 inclusive (Needham and Slater, 1944), indicated clearly that it is uneconomical to stock small trout in natural streams, especially in those streams that contain existing populations of trout.

At the conclusion of the war, emphasis on stocking had shifted from trout of fry and fingerling size to those of legal or catchable size. Continuation of survival studies at Convict Creek necessitated the redesign

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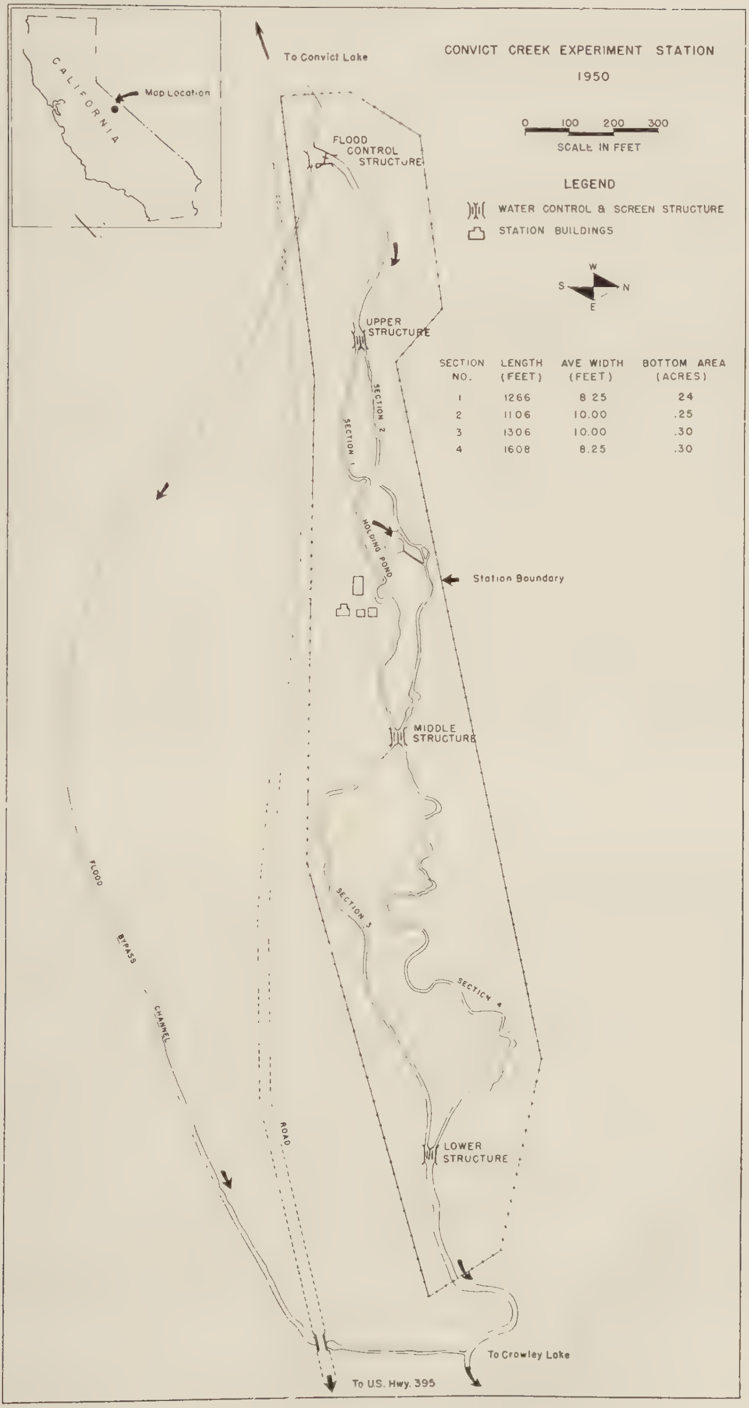
[2] 5.0 to 8.0 inches, total length.



SECTION NO.	LENGTH (FEET)	AVE WIDTH (FEET)	BOTTOM AREA (ACRES)
1	1266	8 25	24
2	1106	10.00	.25
3	1306	10.00	.30
4	1608	8.25	.30

FIGURE 1. Map of station area and experimental stream facilities.

of stream facilities to accommodate the larger fish on a yearlong basis. In 1948, all of the earlier experimental stream facilities were abandoned and the main stem of Convict Creek was placed under control (Figure 1). Three large, reinforced concrete water control and screen structures (designated upper, middle, and lower and illustrated in Figures 2, 3, and 4) were constructed to make maximum utilization of the stream within the experimental area. The upper structure receives the total flow of Convict Creek and discharges it into two lateral channels, each approximately one-quarter mile long. The middle structure

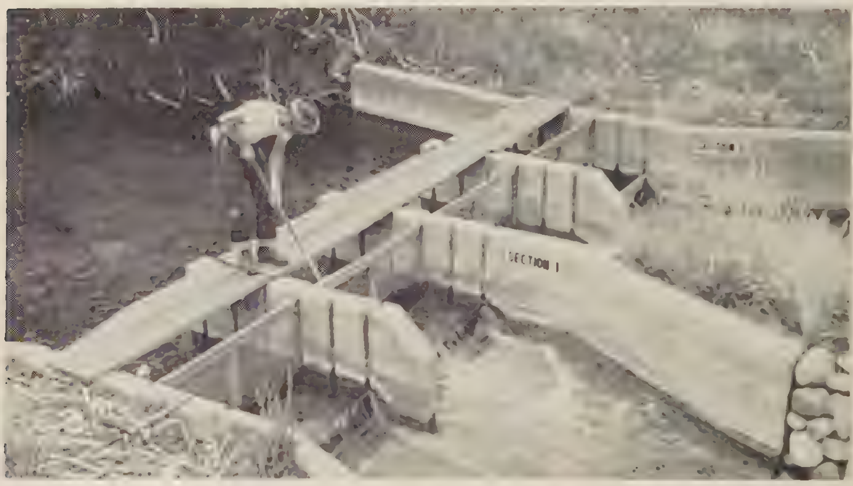


FIGURE 2. Upper water control and screen structure, showing division of main stream into experimental stream Sections 1 and 2. Multiple keyways in walls and piers provide for the use of screens in making temporary fish-holding pens of various sizes. *Photograph by E. Philip Pister, September, 1950.*

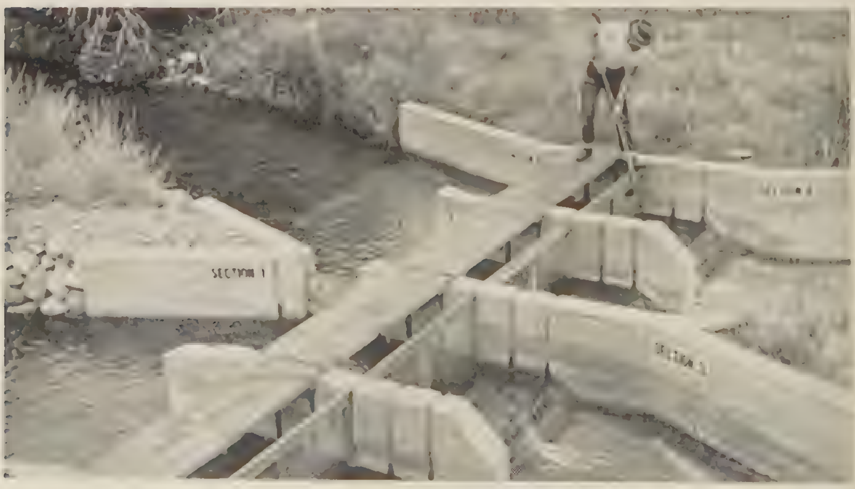


FIGURE 3. Middle water control and screen structure. The sluiceway in the upstream part of the center pier makes it possible, with the use of dam boards and the control of flow at the upper structure, to maintain flow in any three sections while a fourth section is being dewatered. *Photograph by E. Philip Pister, September, 1950.*

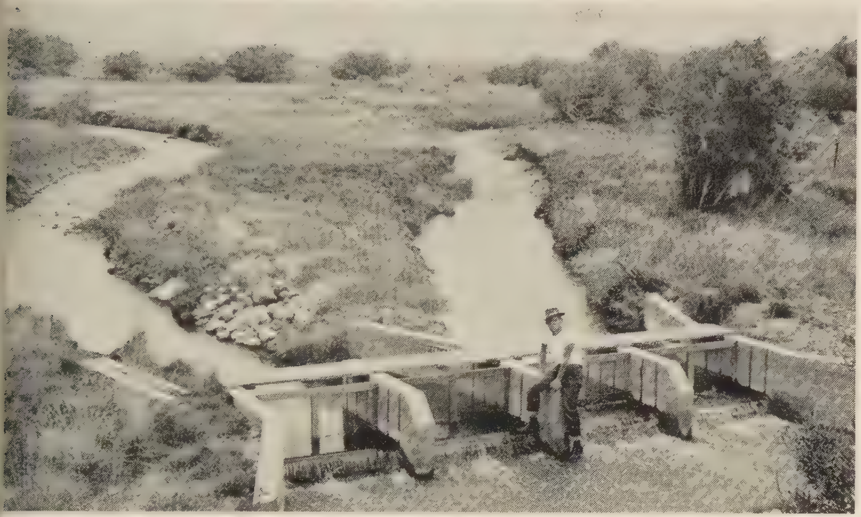


FIGURE 4. Lower water control and screen structure, showing terminal portions of Sections 3 and 4 and discharge of flow into the main stream. *Photograph by E. Philip Pister, September, 1950.*

receives these lateral channels and discharges two other laterals that continue about one-quarter mile to the lower structure, where they are received and discharged into the main stem of Convict Creek. The four experimental stream sections comprise an aggregate length of one mile and a bottom area of approximately 1.1 acres at average summer flow conditions. Total flow through the area is divided equally between the paired stream sections (numbered 1 and 3, and 2 and 4). All of the structures are keyed for flashboards and for the use of vertical, stationary screens covered with 2 by 2, 16-gauge galvanized hardware cloth. The design of the middle structure makes it possible to maintain flow in any three sections while a fourth section is dewatered.

The structures were designed to accommodate flows up to 100 cubic feet per second (c.f.s.) and flows in excess of this amount can be diverted around the experimental area by means of a bypass. Twenty-year runoff records indicate a mean daily flow of 27.7 c.f.s. Extreme flows that occurred during this period were a minimum of 1.3 c.f.s. on January 10, 1951, and a maximum of 227.5 c.f.s. on June 28, 1938. Flow records for the period of the current investigations are summarized in Table 1.

The experimental stream area lies at an elevation of 7,200 feet and is located in Mono County, California, about 35 miles north of the town of Bishop. The controlled stream is typical of many high altitude trout streams not only in the Sierra Nevada but also in other mountain ranges of the West. Conditions throughout the area are natural except for the water control and screen structures that separate the experimental stream sections. Fishing is prohibited.

The climate of the general area is characterized by moderate, dry summers and by moderate to severe winters with heavy snowfall, frequent and prolonged periods of subfreezing temperatures, and almost constant winds, which sometimes attain velocities in excess of 80 miles

TABLE 1

Mean Monthly, Seasonal, and Annual Flows in Cubic Feet Per Second in Convict Creek, May, 1950, to June, 1956

Month/year	May	June	July	Aug.	Sept.	Oct.	Summer mean	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	Winter mean	Annual mean
5/50–4/51	33.3	61.8	42.6	15.7	12.2	7.1	28.8	18.9	23.0	10.6	10.4	8.3	11.2	13.7	21.3
5/51–4/52	30.9	66.2	50.0	23.8	13.5	9.8	32.7	10.7	11.7	14.5	11.7	11.2	13.4	12.2	22.3
5/52–4/53	43.2	98.0	97.1	57.5	25.2	15.9	56.1	10.7	12.3	11.6	7.1	6.3	8.7	9.4	32.8
5/53–4/54	17.2	42.9	63.9	24.6	14.0	10.0	28.8	9.6	7.0	6.7	8.5	9.3	12.6	9.0	18.9
5/54–4/55	40.8	54.4	41.8	18.3	10.8	7.2	28.9	8.3	8.8	9.9	7.4	7.1	6.9	8.1	18.5
5/55–4/56	21.4	74.5	50.9	24.8	13.6	8.8	32.3	8.1	21.5	21.9	14.4	9.2	12.6	14.6	23.5
Mean	31.1	66.3	57.7	27.5	14.9	9.8	34.6	11.1	14.1	12.5	9.9	8.6	10.9	11.2	22.9

May, 1956, 29.7; June, 1956, 101.3

er hour. Winds in winter cause the snow to drift over the stream and ompletely bridge it for varying lengths of time, depending on the everity of the weather. Continuous records of air and water tempera- ures were maintained by means of a Taylor thermograph. These rec- ords are summarized in Tables 2 (air) and 3 (water) for the period of he present studies.

NATURAL POPULATION DENSITY OF WILD BROWN TROUT AND GENERAL METHODS

Prior to reconstruction (1948) and the initiation of the present urvival studies (1950), all resident trout were removed from the main tem of the creek within the experimental area. The area had been losed to angling and other uses for a period of seven years and it was nportant to know the density of the existing, undisturbed population f brown trout in order to form a basis for comparison for the present urvival experiments.

Excluding fry and fingerlings of the year, 1,627 trout with a gross eight of 131 pounds were removed from the three-quarter-mile section f stream. On the basis of area, there was an average of one trout per 0 square feet of stream bottom. By weight, density of the recovered opulation was 120 pounds per acre, and this density was considered o represent the natural carrying capacity of the stream in an undis- urbed condition. However, this population density is not in agreement ith average densities found by Needham et al. (1945) in open and losed sections of Convict Creek in August in four consecutive years 1939 to 1942). In a stream section 126 feet long, closed to angling, hese authors found an average density of 297.1 pounds per acre, hereas in an open section approximately 300 feet long the calculated ensity was 68.7 pounds per acre. Differences in estimates of population ensity could easily be accounted for by sizes of sampled areas—75 ercent of a mile as compared with single, small sections of 2.4 and 5.7 ercent, respectively. Techniques employed in the above population tudies were identical: dewatering the stream, pumping pools dry, and ecovering all trout alive by hand. This method was used throughout he present survival studies and its efficiency has been successfully ested in all of the experimental stream sections.

All catchable-size, hatchery-reared rainbow trout used in the survival xperiments were furnished by the Hot Creek State Fish Hatchery of he California Department of Fish and Game Wild or resident brown rout of comparable size were captured in open sections of Convict Creek. In each experiment, all trout were individually weighed, measured, and marked by the amputation of single fins. At the conclusion f each experiment the fish were again weighed and measured, and lifferences in mean weight, length, and condition for the experimental eriod were calculated. In all of the survival experiments, the only rout present in the experimental areas were the test fish. With the xception of the first year, when yearling rainbow trout of spring- pawning stock were used, all hatchery-reared rainbow trout were the rogeny of fall-spawning stocks and were fish of the year, 6 to 10 nonths old at time of stocking. In contrast with this, brown trout of omparable size used in the experiments were 2 to 3 years old.

TABLE 2

Mean Monthly, Seasonal and Annual Air Temperatures in Degrees Fahrenheit at Convict Creek, May, 1950, to June, 1956

Month/ year	May	June	July	Aug.	Sept.	Oct.	Summer mean	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	Winter mean	Annual mean	Hours below 32 degrees F.
5/50–4/51	48.4	54.5	62.0	58.5	52.1	49.0	54.1	41.4	35.2	30.1	32.2	37.2	43.5	36.6	45.3	2,064
5/51–4/52	50.0	58.3	63.8	54.5	56.8	43.9	54.6	33.0	19.6	18.6	22.0	25.3	39.7	26.0	40.3	3,372
5/52–4/53	51.2	55.9	63.3	60.4	54.2	48.5	55.6	29.1	22.4	31.0	31.2	36.8	42.7	32.2	43.9	2,750
5/53–4/54	44.5	54.6	64.2	59.1	56.2	44.3	53.8	37.5	31.2	29.1	22.9	29.2	45.8	32.3	43.2	2,621
5/54–4/55	55.6	57.5	62.7	58.6	54.6	46.0	55.8	37.3	22.3	15.9	24.3	33.0	39.0	28.6	42.2	2,991
5/55–4/56	*	--	--	65.5	57.5	50.2	--	39.9	33.8	29.8	25.2	38.1	42.7	34.9		
Mean	49.9	56.2	63.2	59.4	55.2	46.3	54.8	36.4	27.4	25.8	26.3	33.3	42.2	31.8	43.0	

May, 1956, 50.2; June, 1956, 59.0.

* Thermograph being repaired.

TABLE 3

Mean Monthly, Seasonal and Annual Water Temperatures in Degrees Fahrenheit at Convict Creek, May, 1950, to June, 1956

Month/year	May	June	July	Aug.	Sept.	Oct.	Summer mean	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	Winter mean	Annual mean
5/50–4/51	47.9	53.0	59.7	59.7	56.3	48.4	54.1	43.6	39.2	34.4	35.5	37.8	44.2	39.1	46.7
5/51–4/52	49.3	55.0	60.5	60.7	58.1	49.2	55.3	41.3	33.3	32.0	33.6	33.6	38.9	35.5	45.4
5/52–4/53	46.8	50.7	55.4	58.7	55.4	52.1	53.2	40.8	35.0	34.6	35.1	37.9	43.3	37.8	45.4
5/53–4/54	45.9	50.9	58.5	59.6	57.3	49.7	53.6	42.5	36.1	32.6	34.7	36.7	45.4	38.0	45.3
5/54–4/55	51.2	53.4	60.1	59.2	55.5	48.4	54.6	42.9	35.6	33.0	34.5	37.9	41.0	37.5	46.1
5/55–4/56	47.3	53.0	63.5	64.6	59.6	52.4	56.7	42.6	37.7	34.9	35.0	39.2	46.3	39.3	48.0
Mean	48.1	52.7	59.6	60.4	57.0	50.0	54.9	42.3	36.1	33.6	34.7	37.2	43.2	37.9	46.2

May, 1956, 52.5; June, 1956, 57.6.

Observation throughout the course of the experiments indicated that edation in Convict Creek was not an important consideration in rvival. No evidence was obtained to indicate the presence of mamalian predators, and fish-eating birds are rare visitors to the area.

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COMPARATIVE SURVIVAL OF SPRING-STOCKED, HATCHERY-REARED RAINBOW TROUT AND WILD BROWN TROUT OF CATCHABLE SIZE

The first four years of survival studies were designed to test as any combinations and stocking densities of hatchery-reared, catchble-size rainbow trout and wild brown trout of comparable size as nditions would permit. Rainbow trout of spring-spawning stock were sed the first year and those of fall-spawning stocks in the other three ars. The spring-spawning trout were hatched and reared from eggs ansferred from Mt. Whitney Hatchery and the fall-spawning trout om eggs of brood stocks maintained at Hot Creek Hatchery. The usual lan was to stock one or more stream sections with rainbow or brown out alone at a certain base density in pounds per acre, and to stock her sections with the two species superimposed at the base density at double density.

The general schedule followed was to stock the experimental stream ctions on May 1, check oversummer survival on November 1, restock e sections, and check overwinter survival the following May 1. These tes are within a week of actual stocking and recovery dates for all st periods. Fish handling and draining of the stream sections required ree or four days. The experimental periods correspond with the open d closed angling seasons, as well as with the semiannual climatic visions hereinafter referred to as "summer" and "winter".

Rainbow trout from the hatchery were handled in accordance with e general technique followed in routine stocking procedures. The st fish were netted at random from production raceways, weighed d counted, and transported four miles from the hatchery to Convict reek by tank truck. At Convict Creek they were released into eviously prepared holding pens in the stream, weighed, measured, arked, and stocked in the sections according to plan. Wild trout

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ow with the California Department of Fish and Game.

were seined from open sections of the stream, and test fish in the same length range as the hatchery trout were selected from them. These fish were transported in 10-gallon cans for short distances from the seining sites to the holding pens. With the foregoing exceptions, treatment of the wild brown trout prior to stocking was identical to that given the hatchery rainbow trout.

First Year, Summer Period

Hatchery rainbow trout had a mean total length of 19.4 centimeters (about 7¾ inches) and a mean weight of 81.0 grams (about 2.9 ounces). They were approximately 10 months old at time of stocking, and averaged 5.6 fish per pound. It was intended to stock the stream sections with wild brown trout of comparable total length, but so few could be found that it was impossible to do so. Brown trout had a mean total length of 13.4 centimeters (about 5.3 inches) and a mean weight of 26.3 grams (about one ounce).

Stocking of the two species was based on numerical equality by area, rather than on comparable density by weight. This procedure produced extreme differences in stocking density by weight. In Section 1, rainbow trout were stocked at the rate of 131 pounds per acre, and the superimposed brown trout at 42 pounds per acre made an aggregate total rate of 173 pounds per acre. Rainbow trout alone in Section 2 were at the rate of 214 pounds per acre, in contrast with 50 pounds per acre for wild brown trout alone in Section 3. The weight density of rainbow trout alone in Section 4 was 250 pounds per acre. Table 4 presents the numerical stocking and recovery data for the first six-month period.

Section 4 was stocked with rainbow trout alone to test the problem of fin regeneration and differential survival due to the amputation of single fins. Specific data on this particular experiment and its results are summarized in Table 7.

In this initial experiment wild brown trout had a higher level of survival in competition with rainbow trout than they did alone, and the survival of competitive rainbow trout in Section 1 was superior to that of noncompetitive rainbow trout in Section 2. The average percentages of survival for both species indicated some advantage for the wild brown trout.

Differences in weight, length, and condition of the two species for the experimental period are summarized in Table 5. Both species declined in body condition, but in doing so demonstrated gains in average weight and length. This situation is undoubtedly due to the fact that the smaller individuals of both species, as demonstrated by the recovery of dead fish, succumbed more readily to the vicissitudes of the environment than did the larger fish. The indicated increases in average weight and length would, therefore, be due as much to differential mortality as to real growth. In stream Section 4, the survival of fin-clipped rainbow trout was superior to that of trout in the unclipped control group. Their survival was also superior to that of similarly marked trout in the other experimental stream sections. The control group in Section 4 had the lowest survival rate of all trout in the various experiments except rainbow trout in stream Section 2. No evidence of fin regeneration was observed among the marked fish at the conclusion of the first six-month period of the study.

TABLE 4

Survival and Loss in the Experimental Stream Sections, Summer Period of May 1 to October 31, 1950

Stream section number	Hatchery rainbow trout							Wild brown trout						
	Number planted	Recovered		Known loss		Unaccounted loss		Number planted	Recovered		Known loss		Unaccounted loss	
		Number	Percentage	Number	Percentage	Number	Percentage		Number	Percentage	Number	Percentage	Number	Percentage
1	176	94	53.4	22	12.5	60	34.1	176	108	61.4	22	12.5	45	25.7
2	301	126	41.9	20	6.6	155	51.5							
3	--	--	--	--	--	--	--	254	143	56.3	7	2.7	104	41.0
4	420	249	59.3	32	7.6	139	33.1							
Total or average	897	469	52.3	74	8.3	354	39.4	429	251	58.5	29	6.8	149	34.7

TABLE 5

Lengths, Weights, and Coefficients of Condition of the Trout at Times of Planting and Recovery, 1950-51

Stocking and recovery dates	Hatchery rainbow trout					Wild brown trout				
	Mean total length		Mean weight		Condition factor "K"*	Mean total length		Mean weight		Condition factor "K"*
	(centimeters)	(inches)	(grams)	(ounces)		(centimeters)	(inches)	(grams)	(ounces)	
5/1/50	19.4	7.6	81.0	2.9	1.10	13.8	5.4	27.4	1.0	1.09
11/1/50	20.4	8.0	85.6	3.0	0.99	15.0	5.9	34.0	1.2	0.96
5/1/51	19.5	7.7	65.3	2.3	0.88	16.7	6.6	37.9	1.3	0.90

* Based on total length (tip of snout to end of caudal rays).

There was no initial heavy mortality among the hatchery trout following planting. In fact, no observed losses occurred during the first six weeks of the study. Thereafter, losses of single fish occurred sporadically. The ratio of "known loss" to "unaccounted loss" was about one to five for both species of trout, and it might be argued that some or a large part of the unknown loss occurred during the early weeks of the experiment. It seems more probable, however, that losses in both categories occurred at the same time and at the same rate.

First Year, Winter Period

Survivors from the summer period were returned to their respective stream sections immediately following the midyear check. However, an accident resulted in the loss of some of the oversummer surviving rainbow and wild brown trout in Section 1, and this accounts for the reduced numbers stocked in that section for the winter period. Rainbow trout retained in the holding pool since May 1 were added to the survivors from Section 2, and wild brown trout from the creek were added to the surviving group to restock Section 3. The survivors from Section 4 were retained in that section without additions.

Planting and recovery data for the winter period are summarized in Table 6. It is evident that the average percentage survival of the rainbow trout was approximately equal in summer and winter of this year and that winter survival of brown trout was significantly lower than summer survival. In consideration of these survival levels, it is important to emphasize the fact that the stocking density for the winter period was only slightly greater than 50 percent of the summer rate for rainbow trout in all sections and for the brown trout in Section 1. Brown trout in Section 3 were stocked for the winter period at a density of 100 pounds per acre, compared with 50 pounds per acre for the summer period. The survival of rainbow trout in competition with brown trout in Section 1 was inferior to that of the noncompetitive rainbow trout groups. Competing brown trout exhibited a higher level of survival than the noncompetitive group. However, there is the possibility that differences in total stocking density, regardless of competition, might have contributed to the observed differences in overwinter survival for this species.

Although the winter was relatively mild (Maciolek and Needham, 1952), especially in terms of snowfall, temperatures were low and the formation of various kinds of ice was prevalent for rather long periods of time. Ice and slush conditions in the stream made it virtually impossible to observe losses and this is evident in the high proportion of unaccounted loss in relation to known loss. The heaviest observed mortalities among the rainbow trout began about the middle of March, when ice formation had ceased and stream temperatures were rising, The mortality rate increased slowly but steadily to the termination of the experiment.

Gross examination of the dead rainbow trout disclosed that all had apparently succumbed to a common cause: secondary fungus infection of deep, abraded areas extending dorsally from the tip of the snout to the occipital region. In some cases, the brain was actually exposed. Examination of the survivors indicated that about 70 percent had similar abrasions and that approximately one-half of these were in various

TABLE 6

Survival and Loss in the Experimental Stream Sections, Winter Period of November 1, 1950, to April 30, 1951

Stream section number	Hatchery rainbow trout							Wild brown trout						
	Number planted	Recovered		Known loss		Unaccounted loss		Number planted	Recovered		Known loss		Unaccounted loss	
		Number	Percentage	Number	Percentage	Number	Percentage		Number	Percentage	Number	Percentage	Number	Percentage
1	82	36	43.9	3	3.7	43	52.4	144	77	53.5	4	2.8	63	43.7
2	174	104	59.8	8	4.6	62	35.6							
3	--	--	--	--	--	--	--	426	146	34.3	3	0.7	277	65.0
4	249	113	45.4	35	14.0	101	40.6							
Total or average	505	253	50.1	46	9.1	206	40.8	570	223	39.1	7	1.3	340	59.6

ges of fungus infection. Observations of the behavior of the fish in e stream failed to reveal the cause of the abrasions. None of the own trout exhibited a similar condition.

In stream Section 4, the percentage survival of fin-clipped trout was wer than of the unclipped control group (Table 7). This is a reversal position, compared with the levels of survival through the summer riod, but the differences are less striking. It is evident that the ampu- tion of either of the ventral fins is in no way deleterious. The survival r the year of marked and unmarked fish in this section was only 27 rcent. There was no evidence of fin regeneration among the marked out at the conclusion of the experiment.

Second Year, Summer Period

The results obtained in the first year's survival experiments were nsidered to be rather good, especially in view of the fact that the ocking rate in certain instances was in excess of the natural popula- on density found in the stream. Although the survival levels for all out were promising, it seemed reasonable to suppose that they might ve been even better if the stocking density had been lower. Accord- gly, stocking for the second year was reduced to a density of 120 unds per acre and the stream sections were stocked numerically as own in Table 8, for the summer period. Section 1 was stocked at the te of 120 pounds per acre (60 pounds per acre rainbow trout and 60 unds per acre brown trout). The numerical difference in the two ecies is due to the differences in their weight as shown in Table 9. ctions 2 and 4 were stocked with rainbow trout alone at the rate of 0 pounds per acre in Section 2 and at 120 pounds per acre in Section Section 3 was stocked with brown trout alone at a density of 120 unds per acre. Average length, weight, and condition for each group trout at times of stocking and recovery are given in Table 9. The tchery trout averaged 8.0 fish per pound.

At the conclusion of the summer period the percentage survival of th species was equal, but disappointingly low and well below the level r the first year. Rainbow trout superimposed on brown trout were rtually decimated, while those in noncompetitive status fared con- lerably better. However, competitive brown trout had more than uble the survival rate of the noncompetitive group. The differences survival levels exhibited by the two species, alone and in combination th each other, cannot be explained. There was nothing to indicate low-average conditions in Sections 2 and 3, the most seriously affected es, and it is difficult to believe that competition accounted for the w level of survival of rainbow trout in Section 1. Starvation experi- ents (Reimers, 1957) show that hatchery-reared rainbow trout can ithstand prolonged periods without food before sustaining mortality tes as heavy as those observed in this particular section. Furthermore, mpetition seemed to favor survival in the experiments of the first ar, when population densities were greater.

In all cases in which the percentage survival was low, the percentage unaccounted loss was high, suggesting that escapement of fish from e sections may have contributed to the losses. Identical screens were ed to retain fish in all sections, however, and all received the same reful surveillance. There was no screen breakage or loss during the

TABLE 7

Results of Fin Amputation Experiment (Rainbow Trout)

Fin amputated	May 1 to November 1, 1950			November 1, 1950, to May 1, 1951			Percentage survival for the year
	Number planted	Recovered		Number planted	Recovered		
		Number	Percentage		Number	Percentage	
Right ventral	140	92	65.7	92	41	44.6	29.3
Left ventral	140	87	62.1	87	38	43.7	27.1
Unmarked (control)	140	70	50.0	70	34	48.6	24.3
Total or average	420	249	59.3	249	113	45.4	27.0

TABLE 8

Survival and Loss in the Experimental Stream Sections, Summer Period of May 1 to November 1, 1951

Stream section number	Hatchery rainbow trout							Wild brown trout						
	Number planted	Recovered		Known loss		Unaccounted loss		Number planted	Recovered		Known loss		Unaccounted loss	
		Number	Percentage	Number	Percentage	Number	Percentage		Number	Percentage	Number	Percentage	Number	Percentage
1	150	27	18.0	15	10.0	108	72.0	169	109	64.5	4	2.4	56	33.1
2	251	95	37.8	8	3.2	148	59.0							
3	--	--	--	--	--	--	--	416	122	29.3	15	3.6	279	67.1
4	350	176	50.3	23	6.5	151	43.2							
Total or average	751	298	39.7	46	6.2	407	54.1	585	231	39.5	19	3.2	335	57.3

period. Opportunity for escapement was slight, and was certainly equal for all groups of trout.

Second Year, Winter Period

Survivors from the summer period were used to restock the sections for the winter period. Section 1 was stocked at the rate of 120 pounds per acre (60 pounds per acre rainbow trout and 60 pounds per acre brown trout). Section 2 was stocked with rainbow trout alone at a density of 60 pounds per acre, and Section 3 received brown trout alone at 95 pounds per acre. Section 4 was not stocked, and its terminal screens were removed to determine whether or not spawning runs of rainbow and brown trout from Crowley Lake (located approximately five miles downstream), were being blocked by the screen structures. Later observations showed that they were far enough upstream to constitute no serious interference. Numerical stocking of the sections may be examined in Table 10, which also summarizes the results of the experiment. Data on the weight, length, and condition of the trout at times of planting and recovery are summarized in Table 9.

The survival levels for both species of trout, as shown in Table 10, were extremely poor in comparison with survivals for the same period in the preceding year. This poor survival may be accounted for by the weather. The winter was the most severe and prolonged of historical record. The first permanent snow, amounting to two feet on the level, fell on November 19, and this was followed by a succession of storms that extended to the middle of April. By midwinter, these storms and their attendant winds had left a snow cover ranging from 5 to 15 feet in depth over the area. The entire stream was bridged with snow and ice, and remained in this condition for four months. During this period, the maintenance of screens was a matter of arduous labor under extremely trying and difficult weather conditions.

At the conclusion of the winter it was apparent that trout had suffered severe mortality not only in the experimental stream sections but also in the creek outside of the closed area. Observations indicated that the overburden of snow and ice could account for trout losses by several means. Most prominent among these were the collapses of the snow and ice cover into the stream that occurred at various times and places throughout the winter. These collapses were large, and the stream was completely dammed where they occurred. The effect was immediate, and trout could be lost in any of three different ways: (1) crushed and/or suffocated directly beneath the mass of snow and ice; (2) suffocated throughout the length of stream dewatered; and (3) left stranded under the snow when the ponded or flooded area above the snow barrier receded. The insulating snow cover also prevented the formation of various forms of subsurface ice that have been shown (Maciolek and Needham, 1952) to be beneficial in making bottom dwelling organisms available to trout in winter. The snow cover also excluded all light, which resulted in the depletion of bottom organisms (Reimers, 1957). Stream bottom rocks were rough to the touch, and were devoid of the periphytic material that is essential to the macroscopic stream fauna.

Screens that were damaged and broken during the winter were replaced as rapidly as possible, but this replacement sometimes required

Lengths, Weights, and Coefficients of Condition of the Trout at Times of Planting and Recovery, 1951-52

Stocking and recovery dates	Hatchery rainbow trout					Wild brown trout				
	Mean total length		Mean weight		Condition factor "K"*	Mean total length		Mean weight		Condition factor "K"*
	(centimeters)	(inches)	(grams)	(ounces)		(centimeters)	(inches)	(grams)	(ounces)	
5/1/51	17.2	6.8	56.4	2.0	1.11	16.7	6.6	37.9	1.3	0.94
11/1/51	18.0	7.1	44.5	1.6	0.76	17.5	6.9	45.9	1.6	0.91
5/1/52	19.0	7.5	47.4	1.7	0.69	18.3	7.2	47.4	1.7	0.77

* Based on total length (tip of snout to end of caudal rays).

TABLE 10

Survival and Loss in the Experimental Stream Sections, Winter Period of November 1, 1951, to May 1, 1952

Stream section number	Hatchery rainbow trout							Wild brown trout						
	Number planted	Recovered		Known loss		Unaccounted loss		Number planted	Recovered		Known loss		Unaccounted loss	
		Number	Percentage	Number	Percentage	Number	Percentage		Number	Percentage	Number	Percentage	Number	Percentage
1	140	1	0.7	6	4.3	133	95.0	151	27	17.9	8	5.3	116	76.8
2	140	15	10.7	4	2.9	121	86.4							
3	--	--	--	--	--	--	--	203	51	25.1	4	2.0	148	72.9
Total or average	280	16	5.7	10	3.6	254	90.7	354	78	22.0	12	3.4	264	74.6

several days. Opportunity for escapement of trout from the stream sections existed at these times, but it is believed that actual escapement must have been exceptionally low or nonexistent. This conclusion is based on the findings that no unmarked trout were found in the sections and that there was no evidence of straying between sections. The opportunity for ingress was equal to that for egress and, since ingress did not occur, it is unlikely that escapement was of serious proportions.

The survival of wild brown trout was almost four times as great as that of the hatchery-reared rainbow trout. This suggests that the wild trout possessed physical stamina superior to that of the hatchery trout in coping with extreme environmental conditions, or that the wild trout had a superior aptitude for utilizing effective shelter. Although the survivors of both species showed slight gains in weight and length, their general condition had declined. Percentage reduction in condition was greater among the brown trout for the experimental period.

Third Year, Summer Period

The unprecedented winter of 1951-52 left a record snowpack in the highlands of the Sierra Nevada. Runoff from this snowpack was also of record proportions, and it can be observed from Table 1 that the mean summer flow in Convict Creek was approximately double that of the other years recorded and that heavy runoff characterized the entire summer period. There were drastic fluctuations in flow, and peak flows in excess of 200 c.f.s. were common in the months of June and July. Because of these flow conditions, stocking of the experimental stream sections was delayed until August 1, and even at that late date in the season it was not considered safe to stock more than 2 of the 4 sections.

In consideration of the results obtained in the 1951-52 survival studies, stocking density was further reduced to a base level of 50 pounds per acre. Table 11 summarizes the numerical stocking and the results at the conclusion of 100 days (August 1 to November 8). Section 1 was stocked at the rate of 100 pounds per acre with hatchery-reared rainbow and wild brown trout at 50 pounds per acre each. Section 3 was stocked with rainbow trout only at a density of 50 pounds per acre. Data on the length, weight, and condition of the trout at times of planting and recovery are summarized in Table 12. The hatchery-reared trout at time of planting averaged 16.1 and 8.0 fish per pound for the two size classes used.

The survival of hatchery-reared rainbow trout in this experiment was considered to be phenomenal. A higher survival rate (96.8 percent) occurred in the group in competition with wild trout than in the group stocked alone at lower density. The survival of 80.6 percent of the noncompetitive group of rainbow trout must also be considered excellent.

The low level of survival among the wild brown trout resulted from an epizootic to which the hatchery trout were not susceptible. Dead and dying brown trout in unusual numbers were first noticed about the middle of August. Observation indicated that brown trout were dying in the open sections of Convict Creek, as well as in Section 1. The condition prevailed for about two weeks and disappeared as rapidly as it had begun. Numerous moribund and dead trout taken from Section 1 and from the stream outside the closed area were examined during the outbreak. General external condition of all trout examined appeared

TABLE 11

Survival and Loss in the Experimental Stream Sections, Summer Period of August 1 to November 8, 1952

Stream section number	Hatchery rainbow trout							Wild brown trout						
	Number planted	Recovered		Known loss		Unaccounted loss		Number planted	Recovered		Known loss		Unaccounted loss	
		Number	Percentage	Number	Percentage	Number	Percentage		Number	Percentage	Number	Percentage	Number	Percentage
1	95	92	96.8	1	1.1	2	2.1	87	32	36.8	4	4.6	51	58.6
3	242	195	80.6	5	2.1	42	17.3							
Total or average	337	287	85.1	6	1.7	44	13.2	87	32	36.8	4	4.6	51	58.6

to be excellent, but gross post-mortem examination revealed the coagulation of the entire blood supply. The condition was a progressive one, with coagulation first appearing in the gills. Several hours elasped between the time of first distress and death. At time of death, blood could be squeezed from the gills as a firm, nonliquid mass.

In terms of the total brown trout population in Convict Creek, it was impossible to estimate the extent of the epizootic. It was certain, though, that all sizes of trout were susceptible and that none of the infected trout recovered. Microscopic examination of blood specimens failed to reveal the cause of the condition.

Third Year, Winter Period

Survivors from the summer period were returned to their respective sections and additional stream-conditioned trout were added to bring the stocking density to 100 pounds per acre (rainbow and brown trout) in Section 1 and to 50 pounds per acre in Section 3 (rainbow trout only). Numerical stocking of these stream sections is summarized in Table 13, together with data on survival and loss. Data on the mean weight, length, and condition of these trout at times of planting and recovery are summarized in Table 12.

The winter was considered average for the area. General conditions may best be described as being about midway between the mild winter of 1950-51 and the record winter of 1951-52. Snow depth averaged from two to five feet, and the entire stream was bridged with ice and snow for approximately two months. Once again, the maintenance of screens and the operation of the stream sections was a difficult and arduous task.

The overwinter survival of the test fish was excellent, especially in comparison with survivals for the two preceding winters. It is remarkable that the percentage survival of hatchery-reared rainbow trout virtually equaled that of the wild brown trout and that the survival levels for both in competition were superior to that of the noncompetitive rainbow trout group at one-half the population density. Loss in condition was slight for both species. The noncompetitive rainbow trout showed slightly improved body condition.

Extended Observation of Third-year Survivors (Rainbow Trout)

Because the survival of hatchery-reared rainbow trout was so good during the year, the survivors were held in the creek an additional 18 months. The history of this group of trout for 27 months in Convict Creek is summarized in Table 14. Survival of this group of trout during the first year was excellent, as previously noted, but the survival rate in the second year dropped to less than one-half the first year's level. The few second-year survivors passed through the third summer with a survival rate approximately equal to that of the first year. After the first year, these fish were held continuously in Section 2, and as mortality continued their density per unit area decreased. It is, therefore, apparent that the carrying capacity of the stream had nothing to do with the survival of these trout. It is equally evident that continuous natural mortality is indeed high among members of an animal group characterized by short life spans. The trout used in this experiment

TABLE 12

Lengths, Weights, and Coefficients of Condition of the Trout at Times of Planting and Recovery, 1952-53

Stream section number	Period	Hatchery rainbow trout					Wild brown trout				
		Mean total length		Mean weight		Condition factor "K"*	Mean total length		Mean weight		Condition factor "K"*
		(centi-meters)	(inches)	(grams)	(ounces)		(centi-meters)	(inches)	(grams)	(ounces)	
1	Planted 8/1/52	16.2	6.4	57.3	2.0	1.351	18.8	7.4	62.6	2.2	0.926
	Recovered 11/8/52	18.1	7.1	57.9	2.0	0.971	20.4	8.0	81.0	2.9	0.949
3	Planted 8/1/52	13.2	5.2	28.1	1.0	1.226					
	Recovered 11/8/52	15.1	5.9	31.0	1.1	0.887					
1	Planted 11/10/52	17.5	6.9	53.4	1.9	0.965	17.3	6.8	50.5	1.8	0.929
	Recovered 4/29/53	18.1	7.1	52.9	1.8	0.866	18.3	7.2	56.3	2.0	0.902
3	Planted 11/10/52	15.0	5.9	31.1	1.1	0.896					
	Recovered 4/29/53	15.2	6.0	34.4	1.2	0.932					

* Based on total length (tip of snout to end of caudal rays).

TABLE 13

Survival and Loss in the Experimental Stream Sections, Winter Period of November 8, 1952, to April 29, 1953

Stream section number	Hatchery rainbow trout							Wild brown trout						
	Number planted	Recovered		Known loss		Unaccounted loss		Number planted	Recovered		Known loss		Unaccounted loss	
		Number	Percentage	Number	Percentage	Number	Percentage		Number	Percentage	Number	Percentage	Number	Percentage
1	102	86	84.3	7	6.9	9	8.8	108	92	85.2	0	0.0	16	14.8
3	209	154	73.7	7	3.3	48	23.0							
Total or average	311	240	77.2	14	4.5	57	18.3	108	92	85.2	0	0.0	16	14.8

TABLE 14

Survival History of Hatchery-reared Rainbow Trout Originally Stocked August 1, 1952

Period	Number planted	Survival		Known loss		Unaccounted loss		Progressive survival (percentage)
		Number	Percentage	Number	Percentage	Number	Percentage	
8/1/52–11/ 8/52	337	287	85.1	6	1.8	44	13.1	85.1
11/8/52– 4/29/53	311	240	77.2	14	4.5	57	18.3	66.5
5/1/53–11/ 1/53	206	82	39.8	13	6.3	111	53.9	29.6
11/1/53– 5/ 1/54	79	25	31.7	9	11.4	45	57.0	9.1
5/1/54–11/ 1/54	24	18	75.0	2	8.3	4	16.7	6.6

were 33 months old from time of hatching to the termination of this experiment.

The sex ratio of the 18 terminal survivors was one to one and they were all in good condition ($K=0.798$). All males were in various stages of sexual maturity, but none of the females had attained any noticeable degree of sexual development.

Fourth Year, Summer Period

Because of the rather confused results obtained during the summer period of the second year and the excellent results of tests in the third year, a base stocking density of 75 pounds per acre was selected to represent an intermediate level for the fourth year. Section 1 was stocked with hatchery-reared rainbow trout and wild brown trout, each at the rate of 75 pounds per acre. Section 2 carried holdover rainbow trout from the third-year survival group. Section 3 was stocked with rainbow trout only of the size (average total length) used in Section 1 and at a density of 75 pounds per acre. Section 4 was stocked with rainbow trout alone at a density of 75 pounds per acre, but these trout averaged 20 percent larger (total length) than those used in Sections 1 and 3.

Numerical stocking of the sections and the results obtained are summarized in Table 15, and data on the weight, length, and condition are summarized in Table 16. At the time of stocking, rainbow trout averaged 14.3 and 6.8 per pound for the two size classes used. In this experiment, the survival of competitive rainbow trout was definitely inferior to that of the noncompetitive groups and inferior to that of wild brown trout with which they were stocked at double density. There was no difference in percentage survival between the two size classes of rainbow trout, and both of these groups exhibited survival levels slightly greater than that for the competitive brown trout. The survival levels in all cases were approximately 50 percent higher than for the comparable period in the second year. Although evidence is inconclusive, this seems to be the only instance in which interspecies competition appeared clear and detrimental to the hatchery-reared trout. Even so, the survival level of the competitive rainbow trout was equal to or greater than that of noncompetitive groups in some of the preceding experiments for an equivalent period of time.

There was no initial heavy mortality among the hatchery trout immediately following planting. Losses, consisting of single fish, were first observed after four weeks and continued sporadically to the close of the experimental period. With the exception of a few emaciated individuals, all dead trout recovered appeared to be in good physical condition and the cause of death could not be determined.

Survival of rainbow trout held over from the third-year experiments was definitely inferior to the survival of the rainbow trout freshly stocked from the hatchery.

Fourth Year, Winter Period

Only two of the four experimental sections were used over the winter. Section 2 continued to carry the hold-over rainbow trout from the third-year experiments, and Section 4 carried its survivors from the summer period at a density of 52.2 pounds per acre. Numerical stock-

TABLE 15

Survival and Loss in the Experimental Stream Sections, Summer Period of May 1 to November 1, 1953

Stream section number	Hatchery rainbow trout							Wild brown trout						
	Number planted	Recovered		Known loss		Unaccounted loss		Number planted	Recovered		Known loss		Unaccounted loss	
		Number	Percentage	Number	Percentage	Number	Percentage		Number	Percentage	Number	Percentage	Number	Percentage
1	260	125	48.1	74	28.4	61	23.5	177	134	75.7	17	9.6	26	14.7
2*	206	82	39.8	13	6.3	111	53.9							
3	312	239	76.6	13	4.2	60	19.2							
4	155	118	76.1	1	0.6	36	23.3							
Total or average	727	482	66.3	88	12.1	157	21.6	177	134	75.7	17	9.6	26	14.7

* Hold-over rainbow trout from third year not included in summary of totals and averages.

TABLE 16

Lengths, Weights, and Coefficients of Condition of the Trout at Times of Planting and Recovery, 1953-54

Stream section number	Period	Hatchery rainbow trout					Wild brown trout				
		Mean total length		Mean weight		Condition factor "K"*	Mean total length		Mean weight		Condition factor "K"*
		(centi-meters)	(inches)	(grams)	(ounces)		(centi-meters)	(inches)	(grams)	(ounces)	
1	Planted 5/1/53	14.2	5.6	31.6	1.1	1.096	17.1	6.7	46.3	1.6	0.916
	Recovered 11/1/53	15.7	6.2	30.2	1.1	0.773	17.8	7.0	54.1	1.9	0.793
3	Planted 5/1/53	14.2	5.6	33.0	1.2	1.153					
	Recovered 11/1/53	16.5	6.5	35.8	1.3	0.792					
4	Planted 5/1/53	17.8	7.0	66.3	2.3	1.248					
	Recovered 11/1/53	19.9	7.8	61.8	2.2	0.739					
4	Planted 11/1/53	19.9	7.8	61.8	2.2	0.739					
	Recovered 5/1/54	20.5	8.1	57.3	2.0	0.666					

* Based on total length (tip of snout to end of caudal rays).

ing and results for the period are summarized in Table 17 and data on the weight, length, and condition of the trout in Section 4 are summarized in Table 16.

TABLE 17

Survival and Loss in the Experimental Stream Sections, Winter Period of November 1, 1953, to May 1, 1954

Stream section number	Hatchery rainbow trout						
	Number planted	Recovered		Known loss		Unaccounted loss	
		Number	Percentage	Number	Percentage	Number	Percentage
2*----------	79	25	31.7	9	11.4	45	57.0
4----------	115	46	40.0	38	33.0	31	27.0

* Hold-over trout from third year.

Winter conditions, with regard to severity and duration, were very similar to those that prevailed during the previous year. Snow depth averaged from two to five feet and the stream was bridged with ice and snow for about two months.

Survival of the hatchery-reared rainbow trout in Section 4 was only 40 percent, in comparison with the survival of 73.7 percent of the rainbow trout stocked in the same section at a density of 50 pounds per acre the preceding winter. However, the third-year trout entered the winter of 1952-53 at an average condition of 0.896, in comparison with 0.739 for the present group. These differences in condition could account for the differences in survival levels for the two groups. It is also important that the overwinter survivors of the third year apparently gained in condition to 0.932, whereas the survivors of the fourth winter reduced in condition to an average of 0.666.

The survival of rainbow trout through their second winter in the stream was relatively low at 31.7 percent, but was surprisingly high in comparison with the survival of only 40 percent of the current year group. It is evident that the condition of trout has a rather considerable bearing on ability to survive, but it is equally clear that certain environmental conditions, as yet undetermined, must be of critical significance.

SUMMARY OF FIRST FOUR YEARS

In the preceding sections the results of comparative survival trials on a seasonal basis have been presented, and the trends of events for each test period have been briefly described. During the four years, weather conditions were represented by a mild winter, by the most severe winter of record, and by two average years. Stocking density of trout ranged from 50 to 250 pounds per acre (initial spring stocking). Competitive stocking at various levels was tested in seven of the eight six-month test periods. The existence of interspecies or intraspecies competition was not demonstrated and survival was not indicated as being influenced by differences in stocking density. In one instance, the full impact of an unknown epizootic was sustained by brown trout alone. In another instance, the partial impact of a fungus infection was felt by rainbow trout alone. Except in those cases where infections were prominent, observed losses of trout were sporadic and without pattern in all experimental periods. There was never a case of high initial mortality among the planted trout.

The gross average percentages of survival for each test period for each species of trout are summarized in Table 18. The resident wild brown trout exhibited better survival than did hatchery rainbow trout in two of three winter periods and in two of four summer periods. The only instance in which hatchery rainbow trout were superior was through the summer period of the third year, when brown trout were decimated by an epizootic to which the rainbow trout were immune. In the summer period of the second year, average survival of the two species was indicated as equal. The grand seasonal averages for the four years, however, indicate slightly superior survival of the rainbow trout through the summer season as compared with superior survival of brown trout through the winter. The average of summer and winter survivals over four years of study was 52.5 percent for hatchery rainbow trout and 50.7 percent for wild brown trout. The interpretation of annual survival was not attempted with the present data of semiannual or shorter periods, since handling losses and other accidental losses sustained in the draining operations at the end of each seasonal period are difficult if not impossible to reconcile on an annual basis. Because gross survival levels of the two species and types of trout were so nearly identical, it is apparent that these trout must be of nearly equal physical vitality and hardiness, at least for the experimental periods considered.

TABLE 18

Percentage Survival of Hatchery-reared Rainbow Trout and Wild, Resident Brown Trout of Comparable Size for Four Years

Year	Summer period		Winter period	
	Rainbow trout	Brown trout	Rainbow trout	Brown trout
1950-51	52.3	58.5	50.1	39.1
1951-52	39.7	39.5	5.7	22.0
1952-53	85.1	36.8	77.2	85.2
1953-54	66.3	75.7	40.0*	(none used)
Averages	60.8	52.6	44.3	48.8

* Not included in calculation of averages for this column to avoid bias in comparison with percentage survival of brown trout. Average winter survival of rainbow trout for four years was 43.2 percent.

SURVIVAL OF FALL-STOCKED, HATCHERY-REARED RAINBOW TROUT OF CATCHABLE SIZE

The fifth and sixth years of the study were concerned with the survival of hatchery-reared, catchable-size, fall-spawning rainbow trout stocked in the fall. These experiments were restricted to rainbow trout and the stocking density in both years was 120 pounds per acre. Trout were stocked on or about August 1, September 1, October 1, and November 1 and the experiments were terminated in June of the following year in both cases. Trout were obtained from the hatchery in the usual manner, but were selected for uniform total length.

Fifth Year

The experimental stream sections were stocked at monthly intervals beginning August 2, 1954, and the experiment was terminated June 7 to 10, 1955. Stocking and recovery data are summarized in Table 19, and data on the weight, length, and condition of the trout at times of planting and recovery are summarized in Table 20. The various lots averaged 6.2 fish per pound.

In this experiment, as in all previous trials, there was no mortality immediately following planting of the various lots of trout. Losses consisting of individual fish were first observed about 10 days after planting and continued sporadically throughout the experimental period, except in that heaviest losses in Section 3 were coincident with extreme winter conditions during late December and through the months of January and February. Snowfall and duration of snow cover was about average for the area, but temperatures were lower than usual. Ice formations were heavier and persisted longer than in previous years, excepting the record winter of 1951-52. The stream was bridged with ice and snow for about nine weeks.

The percentage levels of survival attained by these fall-stocked trout are considered to be excellent, especially in view of the widespread acceptance of the concept that trout stocked at such a time have a very low survival rate and that the procedure is a wasteful one. Actually, the percentage survival of the lots stocked September 3 and November 1 (66.5 and 64.0 percent) is greater than the four-year average summer survival of 60.8 percent for hatchery rainbow trout during periods between May 1 and November 1. The average overwinter survival of stream acclimated rainbow trout (survivors of summer periods) for the previous four years was 43.6 percent, which is a significantly lower rate than for the trout stocked directly from the hatchery in the present experiment. In an earlier experiment, hatchery-reared rainbow trout stocked August 1, 1952, had a survival of 66.5 percent on April 29, 1953 (272 days). This may be compared with the identical survival rate of 66.5 percent for the lot stocked on September 3, 1954, and recovered on June 9, 1955 (280 days), in the present experiment. Of interest in this comparison is the fact that stocking of the trout planted August 1, 1952, was at an average rate of 75 pounds per acre, whereas the stocking density in the present experiment was 120 pounds per acre.

The average survival of the four lots of trout for the experimental period was 54.0 percent. The poorest survival (37.7 percent) was experienced by the lot stocked in Section 3 on October 1. The heavy losses sustained in this stream section were coincident with extreme winter conditions and, although no quantitative evidence has been obtained, the explanation of the disproportionately low recovery of trout is thought to lie in the relative exposure of the section to certain

TABLE 19

Survival and Loss in the Experimental Stream Sections for Fall-stocking Experiment, 1954-55 (Hatchery-reared, Catchable-size, Fall-spawning Rainbow Trout)

Stream section number	Planted		Recovered			Known loss		Unaccounted loss	
	Date	Number	Date	Number	Percentage	Number	Percentage	Number	Percentage
1	9/3/54	200	6/9/55	133	66.5	37	18.5	30	15.0
2	11/1/54	161	6/10/55	103	64.0	26	16.2	32	19.8
3	10/1/54	228	6/8/55	86	37.7	58	25.5	84	36.8
4	8/2/54	234	6/7/55	122	52.1	37	15.8	75	32.1
Totals or averages	--	823	--	444	54.0	158	19.2	221	26.8

TABLE 20

Lengths, Weights, and Coefficients of Condition of Rainbow Trout at Times of Planting and Recovery, 1954-55—English Equivalents for Centimeters and Grams (Inches and Ounces) in Parentheses

Date	Planted			Recovered					Loss in condition	
	Mean total length (centimeters)	Mean weight (grams)	Condition factor "K"*	Date	Days in stream	Mean total length (centimeters)	Mean weight (grams)	Condition factor "K"*	Amount	Percentage
8/2/54	18.7 (7.4)	68.6 (2.4)	1.031	6/ 7/55	310	19.8 (7.8)	54.9 (1.9)	0.700	—0.331	32.1
9/3/54	19.2 (7.6)	70.4 (2.5)	0.992	6/ 9/55	280	19.5 (7.7)	54.7 (1.9)	0.724	—0.268	27.0
10/1/54	19.6 (7.7)	71.4 (2.5)	0.940	6/ 8/55	251	19.9 (7.8)	54.7 (1.9)	0.690	—0.250	26.6
11/1/54	20.7 (8.1)	84.7 (3.0)	0.939	6/10/55	222	20.7 (8.1)	59.6 (2.1)	0.673	—0.266	28.3

* Based on total length (tip of snout to end of caudal rays).

critical winter conditions. It is unlikely that the trout stocked in Section 3 were of inferior physical vitality. All trout used in the experiments were drawn from the same group in the hatchery, and the individuals obtained for stocking the other sections were all in good condition, as evidenced by their survival levels.

The condition of the trout (as measured by their coefficient of condition) at times of planting and recovery is summarized in Table 20. There was a small but general decline in plumpness of the successive lots of trout as they were received from the hatchery. All of the trout except those stocked November 1, 1954, made slight growths in length but all sustained considerable loss in weight and consequently declined in coefficient of condition. The most significant point concerning weight loss is that all four groups of trout, regardless of initial condition, time of planting, and period of residence in the stream, reduced to a common weight level. Among the four lots of trout, the length of residence in the creek ranged from 222 to 310 days, a difference of 88 days. Therefore, nearly all weight loss must have occurred during the initial four-month period following planting. It was further indicated that body weight was maintained after it had reached a certain level. However, the actual and percentage losses in condition indicated a progressive decline in relation to time.

Hatchery-reared trout that are introduced into rapidly flowing waters characteristic of mountain streams have many adaptations to make in order to survive. It appears that one of these is streamlining, especially among trout that are as plump as those produced at Hot Creek Hatchery. The importance of such streamlining or reduction in weight was demonstrated in preliminary experiments designed to test the rates of exhaustion of various trout. Plump rainbow trout fresh from the hatchery, hatchery-reared rainbow trout that had been in residence in the stream for 100 days, and wild brown trout of comparable size that had spent their lives in the creek were compared. The test fish were placed in a metal trough, 20 feet long and 16 by 20 inches in cross section, in which the velocity of the water could be controlled from 0 to 3.5 feet per second. The fish were kept moving by motions of the observers or by agitation of the water. A terminal screen prevented escapement. A test fish was considered exhausted when it could no longer maintain its position in the current and was carried onto the screen. At a current velocity of 3.0 feet per second, fresh hatchery trout reached the point of exhaustion in 5 to 10 minutes, stream-conditioned (100 days) hatchery trout in 20 to 30 minutes, and wild brown trout in 45 minutes to an hour. When disturbance was not maintained, brown trout immediately sought out resting areas of dead water at the corners of the trough, but rainbow trout did not. All test fish recovered quickly after being returned to quiet water. It is obvious that the wild trout exhibited greated stamina. It is equally evident that several months of stream residence are required to enable freshly stocked, hatchery-reared trout to approach the level of fitness of the wild trout.

Sixth Year

The experimental stream sections were stocked at the same monthly intervals as in the preceding year, but the pattern of distribution was changed. Each monthly lot of trout was distributed among the four stream sections, rather than being planted in an individual section. Thus, at the conclusion of the four monthly stocking periods each stream section contained an equal density by weight of each lot of trout. This method was designed to test the degree of relationship between stream quality and overwinter survival, as well as to test the general overwinter survival of trout stocked in the fall.

Stocking and recovery data are summarized in Table 21, and data on the weight, length, and condition of the trout at times of planting and recovery are summarized in Table 22. The four lots of trout averaged 5.2 fish per pound at time of planting. As shown in Tables 20 and 22, the average lengths of the trout used in the two years were the same (19.5 cms. or 7.7 inches), with more variation in the fifth-year fish. The trout used in the current experiment, however, were considerably heavier at time of planting (87.2 grams or 3.1 ounces in comparison with 73.8 grams or 2.6 ounces), with consequent higher average coefficients of condition (1.160 in comparison with 0.975).

Winter conditions were milder than in the preceding year and air and water temperatures were generally higher. Snowfall averaged one to two feet on the level and the stream sections were partially bridged with ice and snow for less than one month.

The overwinter survival of the test fish, as shown in Table 21, may only be described as phenomenal. It is apparent that the high levels of survival were undoubtedly due to the mildness and short duration of the winter and to the physical condition and vitality of the test fish. The average survival of all lots of trout (81.2 percent) was 27.2 percent higher than in the preceding year. The disparity between the percentage survival of the August 1 lot and that of the three later groups indicates that time or period of residence in the stream was not necessarily the sole determinant of loss over the experimental period. Circumstantial evidence indicates that high water temperatures during a short period after planting may bring about heavy later mortality, probably due to an early radical loss of body condition. The mean monthly water temperature for August, 1955, in comparison with the lower temperatures for September, October, and November (Table 3), is suggestive of the probable influence of temperatures near 65 degrees F. on higher mortality of the trout stocked on August 1. Highest water temperatures in Convict Creek are reached in early August and are normally sustained throughout the month.

All lots of trout declined drastically in condition during the experimental period, from an initial average of 1.160 to a terminal average of 0.761. These losses in condition were related to decreases in weight much more than to increases in length and were proportional to the respective periods of residence in the stream. The average percentage loss in condition was 34.4, in comparison with 28.5 percent for the previous years' survivors. However, the terminal coefficients of condition for the fifth- and sixth-year survivors were similar (0.697 and 0.761). This further confirms the assumption made at the conclusion of the fifth-year experiments that reduction in weight of plump hatchery trout is a necessary consequence of exposure to a stream environment.

In the fifth year, heaviest losses were sustained in Section 3, coincident with severe winter conditions, suggesting that this section was in

TABLE 21

Survival and Loss in the Experimental Stream Sections for Fall-stocking Experiment, 1955-56
(Hatchery-reared, Catchable-size, Fall-spawning Rainbow Trout)

Lot number	Planted		Recovered			Known loss		Unaccounted loss	
	Date	Number	Date	Number	Percentage	Number	Percentage	Number	Percentage
1	8/1/55	174	6/4–6/56	110	63.2	17	9.8	47	27.0
2	9/1/55	179	6/4–6/56	152	84.9	6	3.4	21	11.7
3	10/1/55	169	6/4–6/56	150	88.7	2	1.2	17	10.1
4	11/1/55	158	6/4–6/56	140	88.6	4	2.5	14	8.9
Totals or averages	--	680	--	552	81.2	29	4.3	99	14.5

TABLE 22

Lengths, Weights, and Coefficients of Condition of Rainbow Trout at Times of Planting and Recovery, 1955-56— English Equivalents for Centimeters and Grams (Inches and Ounces) in Parentheses

Lot number	Planted				Recovered					Loss in condition	
	Date	Mean total length (centimeters)	Mean weight (grams)	Condition factor "K"*	Date	Days	Mean total length (centimeters)	Mean weight (grams)	Condition factor "K"*	Amount	Percentage
1	8/1/55	19.4 (7.6)	85.1 (3.0)	1.156	6/6/56	311	21.0 (8.3)	66.5 (2.4)	0.711	—0.445	38.5
2	9/1/55	19.4 (7.6)	82.6 (2.9)	1.112	6/6/56	281	20.6 (8.1)	63.9 (2.3)	0.709	—0.403	36.2
3	10/1/55	19.6 (7.7)	88.1 (3.1)	1.156	6/6/56	250	21.3 (8.4)	77.6 (2.8)	0.801	—0.355	30.7
4	11/1/55	19.7 (7.8)	93.3 (3.3)	1.217	6/6/56	220	21.3 (8.4)	80.7 (2.9)	0.825	—0.392	32.2

* Based on total length (tip of snout to end of caudal rays).

me way inferior to the others as a habitat for trout. A detailed sur- y indicated similarity of pool quality among the sections, but con- lerable variation in numbers of pools in relation to stream length. ream Section 3 had 0.61 pools per 100 feet, in comparison with 0.71 Section 1, 1.35 in Section 2, and 0.87 in Section 4. In the sixth year, fferences in overwinter survival among the stream sections were small d did not conform to the indicated differences in stream quality as easured by pool numbers (Section 1, 77.5 percent survival; Section 2, .0 percent; Section 3, 87.1 percent; Section 4, 74.9 percent). The ghest level of survival among the sections occurred in stream Section where the lowest survival was found in the fifth year. The compari- n of survival results in Section 3 between the two years is not a und one, owing to differences in winter conditions, yet it is apparent at the superior shelter in Sections 2 and 4 did not result in higher xth-year survival in these sections. These results suggest that the elter qualities of a small stream probably influence first-winter sur- val of hatchery trout under stringent winter conditions, but not in ilder circumstances.

CONCLUSIONS

It is evident from these experiments that rainbow trout hatched and ared to catchable size at Hot Creek Hatchery, of both fall-spawning d spring-spawning stock, exhibited an ability to survive equal to that resident wild brown trout of comparable size. It is also clear that the tchery trout were capable of competing with wild brown trout of e same size, even though the hatchery fish were compelled to make ther drastic adaptations to the wild and entirely foreign environ- ent. There was no evidence to indicate that the survival of the tchery trout was influenced by the absence of the processes of natural lection during early life stages in the hatchery. If the hatchery trout ssessed abnormal physical condition due to fish-cultural techniques, d to stocking practices and methods, their abnormalities evidently ere not critical factors in their ability to survive.

If it is true that hatchery trout are generally inferior to wild trout, en it is only reasonable to infer that the rainbow trout produced at ot Creek Hatchery are demonstrably superior in quality and that e reason or reasons for this superiority must be found in the hatchery d its operational procedures. Further tests are planned to determine hether trout of identical genetic stock and hatching origin, reared at ot Creek and at other California hatcheries, exhibit similar or differ- t survival rates after being stocked in the stream.

Differences in stocking density within the range tested seemed to ve little or no effect on survival, which suggests that our knowledge stream carrying capacity and the factors that influence that capacity indeed scant.

It was demonstrated beyond reasonable doubt that mortality in small reams is indeed high among wild trout, as well as among hatchery- ared trout. However, were the observed losses ''high'' or were they rmal for the test periods in consideration of the species and origins trout utilized? We have no answer to this question, but the experi- ental evidence indicates that time is the grim reaper—that mortality rogresses with time and that the mortalities experienced in the trials are probably within the yearly expectation of natural death. It is therefore of paramount importance that hatchery-reared trout of catchable size be stocked immediately prior to and during the open season in areas of heavy angling pressure in order to realize greatest benefits. This is in confirmation of generally accepted practice, but the concept that hatchery trout so stocked would not be available to anglers a few weeks after stocking is untenable. Equally untenable are the concepts that overwinter survival of hatchery-reared trout is always poor, and that these trout suffer heavy mortality immediately after planting or during short periods following planting. Actually, fall-stocked trout exhibited higher survival levels than those stocked in the spring, considering equal periods of residence in the stream. However, in winters where conditions are extreme and protracted, mortality is exceptionally high and more drastic among hatchery-reared trout than among wild trout.

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ANOTHER RECORD OF THE RARE ARK, *EUPROTOMICRUS BISPINATUS*, OM THE PACIFIC OCEAN.—On April 3, 6, at a night-light station occupied by the re- rch vessel CHARLES H. GILBERT of the Pacific eanic Fishery Investigations, a female specimen an unusual pelagic shark, *Euprotomicrus bi- natus* (Quoy and Gaimard), 242 mm. in total gth, was dipnetted by the authors. The position capture was 32°46′N., 176°42′W., approximately miles north of Midway Islands. The EDO fathometer indicated the depth of the ocean in that region to be about 2,600 fathoms, and the surface temperature was 62.5°F. When first seen, the shark was cruising slowly on the surface which was illuminated by the deck lights of the ship.

Recent descriptions of this rare and peculiar shark are given by Hubbs and McHugh (1951, Calif. Acad. Sci., Proc. IV, 27(6) : 159–76) and also King and Ikehara (1956, Pacific Science, 10(1) : 17–24).—TAMIO OTSU AND HOWARD O. YOSHIDA, *U. S. Fish and Wildlife Service, Honolulu, Hawaii.*

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THE RANGE OF THE SEA SCALLOP

By J. A. Posgay

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The range of the sea scallop, *Placopecten magellanicus* (Gmelin), has been variously reported to be from Labrador to New Jersey (Pratt, 1935; Miner, 1950), Newfoundland to New Jersey (Morris, 1947), and Labrador to Cape Hatteras (Abbott, 1955). A search of the literature and major museum collections has been made in an attempt to clear up this confusion among the most generally available manuals. From the evidence gathered, the limits seem to be from the north shore of the Gulf of St. Lawrence to Cape Hatteras.

Since the sea scallop is an important commercial mollusk, the United States and Canada maintain records of the location and extent of their sea scallop fisheries. These records show that sea scallop beds of sufficient extent and density to support a fishery occur from Port au Port Bay, Newfoundland (Latitude 48° 30′ N) to the Virginia Capes (Latitude 36° 50′ N). The animal probably occurs both north and south of the limits of the fishery.

The uttermost limit of the range of any sedentary marine animal is usually a vague and shifting line. A specific locality may be unsuitable for survival in most years, but in occasional years the environmental stresses may be reduced to the point where some fraction of the hardier members of a population can survive and grow. Therefore, the fringes of the range can be expected to produce only a thin population in occasional years.

Whiteaves (1901), after investigating the records of every major expedition which had collected in Eastern Canada, said that the most northern locality in which the sea scallop has been dredged was Caribou Island, Province of Quebec. His reference is Packard (1867). Caribou Island (Lat. 51° 25′ N, Long. 57° 39′ W) is well inside the Gulf of St. Lawrence. No more northerly record has been found in the literature which has accumulated since Whiteaves' time.

The only evidence that I have found to support the idea that the sea scallop occurs off Labrador is one shell (No. 27271) in the mollusk collection of the United States National Museum.

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SOME ASPECTS OF THE RELATION BETWEEN STREAM FOODS AND TROUT SURVIVAL[1]

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It is known that large losses of both wild and hatchery trout may occur in winter, particularly in smaller streams exposed to severe weather conditions, but there is little established knowledge of the factors responsible for the bulk of such mortality. Continuous direct observation of the natural stream environment or of the fish themselves is impossible in the critical periods. The carcasses of trout, when they can be found, seldom show reliable evidence of the cause of death. Although diseases, predation, and various minor accidents always contribute to the mortality, the influence of these factors in most winter stream situations is too small to account for the heavy losses experienced in many areas. There follows the assumption that winter trout mortality in small, exposed streams is related primarily to lack of nourishment, to severely damaging physical changes in the habitat, or to a combination of the two. Needham and Slater (1944) and Needham, Moffett, and Slater (1945) suggested the probable importance of cold water, ice, and snow conditions as agents of winter trout mortality in streams. The work of Maciolek and Needham (1952) at Convict Creek, California, suggested that further exploration of the winter food problems of trout might clarify the causes of mortality.

The present study was conducted to obtain more information on (1) winter trout food and feeding, (2) the speed and effectiveness of trout digestion at various water temperatures, and (3) the effects of prolonged starvation on the condition and viability of trout in various seasons. These three aspects of the food problem were studied in the stream sections and small experimental hatchery at the Convict Creek Experiment Station of the United States Fish and Wildlife Service. The station is located in Mono County, California, on the eastern slope of the Sierra Nevada, at an elevation of 7,200 feet.

Convict Creek in the area of study is 6 to 15 feet wide, has a bottom of gravel and rubble with frequent long riffles but few deep pools, and follows a relatively straight course on a grade of about 2 percent. The creek is typical of many alpine trout streams, and of streams at lower elevations in regions of severe winters, in that it is exposed nearly every winter to snow and ice cover, long periods of very low water temperature, and radical changes in rate of flow within the daily cycle.

The period of study extended from April, 1952, to June, 1956. Stream food observations were made in April, 1952, and in February and March, 1953, to represent late winter stream conditions in the respective years. Additional postwinter samples were taken in April, 1956. Resident brown trout were taken for stomach analysis in February, 1953. Digestion experiments were conducted when stream temperatures were in the desired ranges, between October, 1954, and February, 1955. Starvation trials with brown and rainbow trout began in December, 1953, and were repeated as other stream work permitted until June, 1956.

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The assistance of Fishery Research Biologists H. D. Kennedy, B. D. Combs, and E. P. Pister [2] in winter sampling, care of experimental fish, and other field work leading to the preparation of this report is gratefully acknowledged. Special thanks are extended to Reed S. Nielson, Chief of California-Nevada Inland Fishery Investigations, United States Fish and Wildlife Service, for advice and assistance throughout the study. Rainbow trout were obtained from the Hot Creek State Fish Hatchery through the cooperation of the California Department of Fish and Game.

WINTER FOOD AND FEEDING

Because nearly all semiaquatic insects overwinter in immature aquatic form, the winter half of the year is often thought of as the season of abundant food for trout in streams. In many situations it might be possible to demonstrate greater per-unit-area abundance of stream-bottom organisms in winter than in summer. Reduced stream flow would contribute to the indication of abundance, however, and the lessened accessibility of many food forms at low or partially icebound water stages might result in the suggestion of a nonexistent food advantage for trout. It should not be inferred, particularly where the winters are long and cold, that available trout foods in a stream are most abundant in winter. The supply may be better or poorer than in summer, depending on the extent to which the physical agents of winter affect the stream.

The effect on the stream bottom of prolonged surface ice or snow cover is to reduce light, periphytic algae, and grazing organisms of food importance. Anchor ice, which forms in cold weather on the bottoms of trout streams in many localities, usually dissipates each day and in doing so may increase the temporary availability of bottom organisms by dislodging them and setting them adrift. However, repeated anchor ice formation in a small stream also results in bottom scouring by sudden releases of water, with the bottom fauna of affected riffle areas inevitably reduced as the season progresses. Ice and slush dams formed by the accumulation of released anchor ice further deteriorate the stream bottom habitat by exposing areas to partial drying, freezing, and rewatering. The total effect is a gradual depletion of available trout food through the winter.

Bottom Foods

To continue the pattern of sampling done in the relatively mild winter of 1950-51 (Maciolek and Needham, 1952), a series of square-foot riffle bottom samples was taken in Convict Creek at the end of an extremely severe winter (1951-52) and in the second half of an intermediate or average winter (1952-53). Results are presented as coarse indications of comparative productivity, with the realization that an expression of the general abundance of stream bottom foods that is based on a few samples is inadequate, however carefully the sampling areas may be chosen or the measurements made. The tests conducted by Needham and Usinger (1956) established that quantitative estimates of invertebrate productivity in a stream section are statistically unreliable unless they represent impractically large numbers of bottom samples.

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[2] Now with the California Department of Fish and Game.

In 1952, from early January to mid-April, the entire width of the creek in most of the study area was bridged by snow and ice. The bridges were caused by heavy drifts of snow which filled and covered the stream channels, and by slush or ice dams which subjected stream areas to surface freezing. Occasionally such covers collapsed under the weight of new snow, forming backwaters that froze to strengthen or create other bridges upstream.

In the darkness under the bridges, rock became devoid of algal growth, the basic food supply of larger bottom organisms. Anchor ice did not form, but surges of water and slush accomplished the same effect on some parts of the stream bottom as would anchor ice. Although they were more extensive than usual at Convict Creek in 1952, these bridging formations are common on northern or alpine inland trout streams and warrant consideration as an influence on bottom food abundance. The deleterious effects of these conditions on the trout food fauna may be seen in the results of a weight analysis of 12 bottom samples taken under and at the edges of ice bridges on April 17. These samples indicated a standing crop of 21.4 pounds (blotted wet weight) of organisms per acre (36 organisms per square foot), which is meager when compared with 134 pounds per acre (373 organisms per square foot) for five samples in February, 1942, and 109 pounds per acre (organisms per square foot not available) for a five-year average of 225 May-to-September samples (Maciolek and Needham, 1952). The average of 12 samples taken in open riffles on April 25, 1952, a week after the stream had begun to clear of ice, yielded a slightly improved estimate of 32.4 pounds per acre (41 organisms per square foot).

The same groups of insects were dominant in the winter bottom samples of all years for which data are available (Table 1), and a comparison of average numbers per square foot may be made. Between January 1 and March 31, 1951, the stream was largely open and was subjected frequently to the influence of anchor ice and frazil ice (floating ice crystals). Riffle bottom samples within this period yielded an average of 107 organisms per square foot. In mid-April, 1952, when sections of the stream first became accessible for sampling, numerical abundance of all food organisms was very low. The average number per square foot was 36. By April 25, when the water had begun to warm and stream ice formations had largely disappeared, samples indicated an average of 41 organisms per square foot. In early 1953, periods of partial stream bridging alternated with periods of open water and extensive anchor ice formation Samples taken in February and March, 1953, indicated standing crops of 139 and 162 organisms per square foot of riffle bottom.

With respect to snow and the bridging of the stream, the months of January, February, and March, 1953, were considerably less severe than the same months in 1952 but somewhat more severe than those months in 1951. However, the bottom fauna crop during this period

TABLE 1

Comparison of the Numbers and Percentages of Riffle Bottom Organisms From Convict Creek in 1942,* 1951,* 1952, and 1953

Group of organisms	1942 February 9 and 10		1951 January 15 to March 22		1952 April 17		1952 April 25		1953 February 3		1953 March 9 to 12	
	Number† and stage	Percentage	Number and stage	Percentage	Number and stage	Percentage	Number and stage	Percentage	Number and stage	Percentage	Number and stage	Percentage
Ephemeroptera	995 (n)	53.4	258 (n)	21.8	43 (n)	10.0	59 (n)	11.9	580 (n)	34.7	591 (n)	30.4
Trichoptera	237 (l) 1 (p) 1 (a)	12.8 --	346 (l) 1 (p)	29.3 --	170 (l) 19 (p)	44.0 --	147 (l) 6 (p)	30.9	378 (l)	22.6	603 (l)	31.1
Diptera	351 (l) -- --	18.8 -- --	140 (l) 2 (p) 5 (a)	12.4 -- 	91 (l) -- 	21.2 -- 	104 (l) -- 	21.0 -- 	297 (l) 2 (a)	17.9 --	323 (l) 8 (a)	17.1
Coleoptera	162 (l) 18 (a)	9.7 -	151 (l) 39 (a)	16.0 -	2 (l) 1 (a)	0.7 -	6 (l) 2 (a)	1.6 --	82 (l) 21 (a)	6.1 --	77 (l) 13 (a)	4.6
Plecoptera	10 (n) --	0.5 --	37 (n) 1 (a)	3.2	3 (n)	0.7	12 (n)	2.5	18 (n)	1.1	12 (n)	0.6
Oligochaeta	79	4.2	139	11.7	81	18.8	149	30.1	265	15.8	304	15.7
Miscellaneous	11	0.6	67	5.6	20	4.6	10	2.0	30	1.8	10	0.5
Totals	1,865		1,186		430		495		1,673		1,941	
Average number of organisms per square foot	373		107		36		41		139		162	
Number of samples	5		11		12		12		12		12	

* Data from Maciolek and Needham (1952).

† Abbreviations used: l

appeared greater in 1953 than in 1951. If anything may be said about these differences in food abundance, beyond the observation that they may be within a range of population fluctuation not controlled by physical conditions of the season, it is that populations of bottom dwelling organisms in a small stream are apparently harmed less by partial snow and ice cover than by repeated exposure to the radical changes in flow that accompany subsurface ice action.

Drift Foods

Drift net samples, obtained by anchoring the square-foot sampler in the current for 15-minute periods at various times and points in the stream, yielded results for February and March, 1953, that were comparable to those for the same months of 1951. The similarity of taxonomic groups composing the drift foods in all sampling periods is evident in Table 2. Immature forms of Ephemeroptera, Trichoptera, and Diptera were dominant. These formed 80 to 97 percent in the aggregate of drift foods available during the 1951 and 1953 sampling periods, and they were set adrift in rough proportion to their abundance on the stream bottom (Table 1). Drift nets could not be fished in early 1952, but the paucity of bottom organisms in April of that year suggests that drift foods were also scarce during much of the 3½-month period that the stream was covered.

TABLE 2

Numbers and Percentages of Organisms Taken From Convict Creek in 36 Drift Net Samples, February 4 Through March 27, 1953

Group of organisms	February 4 to 6, 1953		March 12, 1953		March 27, 1953	
	Number	Percentage by number	Number	Percentage by number	Number	Percentage by number
Ephemeroptera	108	63.2	93	62.0	99	41.6
Trichoptera	30	17.5	17	11.3	21	8.8
Diptera	24	14.0	36	24.0	102	42.9
Coleoptera	2	1.2	4	2.7	5	2.1
Plecoptera	1	0.6				
Oligochaeta	5	2.9	--	--	1	0.4
Miscellaneous	1	0.6	--	--	10	4.2
Totals	171	--	150	--	238	
Average number of organisms per 15-minute drift	14.2	--	12.5	--	19.8	
Number of 15-minute sampling periods	12	--	12	--	12	

Between February 19 and March 8, 1951, the average number of drifting organisms collected per 15-minute drift net sample was 14.4 (Maciolek and Needham, 1952). The average 15-minute yield of 36 drift net sets made in three periods between February 4 and March 27, 1953, ranged from 12.5 to 19.8 organisms (Table 2), with a mean of 15.5 organisms. Weather in February and March of the two years was roughly similar, although 1953 was characterized by more snow, as mentioned previously, and by slightly lower temperatures.

Bottom and drift foods were sampled again in April, 1956, to obtain an estimate of drift food abundance in relation to quantity of bottom foods at a time after all winter disturbances had passed, but before the advent of increased spring runoff and prior to the appearance of leaves on insect-harboring streamside trees. The average yield of six drift net samples at this time was only 7.3 organisms per 15-minute set, although the average yield of six riffle bottom samples (137 organisms per square foot) indicated a supply of bottom foods equal to that found in early February (139 organisms per square foot).

Twelve drift net samples (February 4 to 6, 1953) were divided into four sets during increased flow following the dispersal of anchor ice and slush, and eight sets at times in the afternoon when the flow was free but not influenced by ice dispersal. This division resulted in an indication of slightly increased drift food availability during higher water (17 organisms per 15-minute set) over that found in normal flow (13 organisms per set), but the indication of feeding advantage is less dramatic than what may be gained by observing trout in the stream at such times. As noted by Maciolek and Needham (1952), trout react strongly to increases in flow and drifting particles. During observations in February, 1953, trout fed avidly among clumps of ice in the surges of water, but remained in hiding at times of lower water. As will be shown by analysis of stomach contents, however, there was little selectivity in such feeding. Many of the available drifting organisms were missed while the trout were attacking bits of debris.

The foregoing figures for winter drift food availability may not be protracted over 24 hours or even 12 hours per day, since disturbance of the stream bottom is limited to daylight hours when ice is in motion. At other times the flow is usually reduced and the fish must forage for their food. Frequently in winter these small numbers of drifting bottom organisms are the main source of food for trout in the stream, for when ice in its various forms is present the fish are free to move about in only a fraction of the normal time and area.

Feeding

One occasionally hears the opinion that, due to lowered metabolism, trout existing in a seasonal state of extremely cold water become torpid, or at least inactive and indifferent to food, depending on the habitat. The observations reported by Maciolek and Needham (1952) and subsequent winter observations in the same area indicate that activity of acclimated trout does not decline appreciably with the seasonal reduction of stream temperature, and that the trout feed whenever food is available—even when the water runs at freezing point and is filled with ice spicules. Reduced winter feeding among healthy stream dwelling trout should be attributed for the most part to scarcity or unavailability of food, not to lack of interest in food.

Winter food conditions of Convict Creek for critical parts of three winters have been cited and described in foregoing sections. The evience of actual availability and utilization of this food must be found the stomachs of the trout. In 1952, no resident trout could be found ntil the latter part of April, too late for an analysis of stomach ntents to be representative of feeding in the icebound stream. On ebruary 17, 1953, 66 brown trout were netted from open, "natural" ections of the creek (i.e., sections that were not being used to support her experimental fish). At this time, the stream had been subjected snowstorms and low temperatures, resulting in ice and snow bridging nd disturbance by anchor ice cycles, for well over a month and the ice nditions still prevailed. The results of an analysis of stomach contents these fish are presented in Table 3.

TABLE 3

Stomach Contents of 66 Brown Trout Taken From Convict Creek, February 17, 1953 *

Classification of food item	Number	Percentage by number	Volume in cubic centimeters	Percentage by volume
phemeroptera	314	42.8	0.7	6.9
richoptera	123	16.8	1.3	12.9
iptera	246	33.5	0.5	4.9
oleoptera	38	5.2	0.4	4.0
lecoptera	5	0.7	0.6	5.9
ther organisms	2	0.3	0.1	1.0
rout eggs	5	0.7	0.4	4.0
ebris†	--	--	6.1	60.4
Total	733	--	10.1	
verage per stomach	11.1	--	0.16	

* Trout averaged 17.2 cm. (6.8 in.) and ranged from 11.6 to 22.6 cm. in total length (tip of snout to end of caudal rays).

Sand, pebbles, pine needles, leaf ribs, twigs, bark, and other dead plant parts.

The 66 stomachs contained 733 organisms or 11.1 per fish, compared vith 14.5 per fish in 40 brown trout caught during the first three nonths of 1951. As would be expected in view of their relative abun-ance in the bottom fauna, immature forms of Ephemeroptera, Diptera, nd Trichoptera predominated numerically among ingested foods. ligochaetes were indicated as highly inaccessible. Although they ormed 15.8 percent of the number of organisms found in bottom amples in the same month (Table 1), only a fragment of one of these vorms was found in one out of 66 stomachs. Trout eggs were indicated s a casual food. The five eggs listed in Table 3 were found in two tomachs. The average volume of stomach contents was 0.16 cc. per sh, which is only 55 percent of the average stomach volume noted in 951 (0.29 cc.). Two of the 66 stomachs were empty, but none was lled or even half-filled except by virtue of containing one or two large rganisms.

The outstanding feature of the food analysis was the large proportion f nonnutritious material found in the stomachs. By volume, 60.4 percent of all material ingested consisted of indigestible debris (Table 3), so that the average stomach contained only a little over 0.06 cc. of actual food. Feeding by this group of trout prior to capture was limited by ice to times when water releases made drift foods available. The amount of debris in stomachs indicates that there was little or no discrimination between food and nonfood particles in such feeding. The relatively insignificant volume of organisms per stomach further indicates that food was not easily obtained, even though the trout actively sought it.

DIGESTION EXPERIMENTS

The ability of trout to digest and utilize winter food was studied as a factor that could bear on the problem of survival in relation to food. Leonard (1941) suggested the possibility that trout may derive little nourishment from natural feeding in cold weather, and that food supplies during the coldest part of the year, therefore, may not be a critical factor in the success of trout. Hess and Rainwater (1939) attempted to test the relative digestibility of several natural trout food organisms by estimating the percentages of single organisms that remained in trout stomachs at various times after feeding. They demonstrated incidentally that low water temperature has a marked inhibitive effect on the rate of digestion.

The principal objective of the present experiments was to determine the extent to which digestion of natural food organisms is impeded by low water temperatures. It was considered that the time required for complete digestion of a standardized meal would provide the most informative measure of digestive efficiency at a given water temperature.

Preliminary feeding trials in 1953 resulted in the selection of three easily available and readily ingested organisms to represent soft-bodied, intermediate, and hard-bodied natural stream food forms. The aquatic oligochaete *Helodrilus tetraedrus* is common in Convict Creek and has a soft integument that is almost devoid of chitinous substance. An amphipod (*Gammarus lacustris*) is abundant in nearby Hot Creek. The body of this scud or so-called freshwater shrimp is rendered somewhat more difficult to digest by its covering of delicate chitinous plates. The larva of a locally abundant caddisfly (*Arctopsyche* sp.), with its heavily armored head and thorax and its somewhat leathery abdominal integument, represents a comparatively hard-bodied form. Since individual handling was necessary, size as well as degree of chitinization was considered in the selection of these organisms. Average weight indices of the three organisms were 32, 18, and 16 per gram, respectively.

Simulation of natural feeding was attempted in the 1953 trials. Known numbers and weights of the three types of food organisms were dropped to individual trout in partitioned hatchery troughs from a concealed position in the loft above. Although nearly all of these trout were willing to feed, a few were nervous for hours or days and ignored the items offered. Too much time was involved in bracketing the time required for complete digestion by several fish of a given type meal at the existing stream temperature. The results of the preliminary digestion trials were therefore inconclusive. Feeding was continued at times of various temperature ranges and it was clearly observed that ost trout were eager to feed even in such artificial circumstances at ter temperatures down to the freezing point. This was true for wild well as hatchery trout. Condition likewise had little influence.

Beginning in October, 1954, a series of force-feeding experiments as started, again with oligochaetes, amphipods, and caddisfly larvae. inbow trout were used as experimental subjects because of their ailability in sufficient numbers of reasonably uniform catchable size .5 to 8.0 inches, total length). Preliminary trials had not indicated y difference in digestive efficiency between rainbow and brown trout.

Force-feeding was accomplished either by inserting food organisms the esophagus singly with a round-nosed forceps, or by introducing entire meal into the stomach with a glass tube and plunger. Standard nall meals of 0.5 gram were given in all feedings to minimize the ndling time for each fish. Except for temporary respiratory distress, ill effects among the experimental fish resulted from this method of eding. Digestion was considered complete when part of the digestate ad been eliminated and the balance was found in the lower intestine ith no soft tissue remaining. Although this endpoint is coarse, it is cognizable and it takes into account the entire meal. The number of ours required for complete digestion was determined by feeding 20 to) trout at one time and periodically examining the digestive tracts of ree or four specimens as the expected time approached.

The digestion trials were extended over five months (October to ebruary) to intercept the desired temperature ranges, since water mperatures could not be strictly controlled except by the addition of ow to prolong minimum temperatures. A tendency toward constant mperature in the feeding troughs, caused by tempering of the supply ater in over one-quarter mile of four-inch underground pipe, gave me advantage in the selection of feeding periods to include the nallest possible stream temperature fluctuations. Digestion tests were ade in four temperature ranges between 32 and 53 degrees F. to rep- esent fall and winter stream conditions. In connection with the lowest nge (32 to 33 degrees) it may be mentioned that water in motion egins to freeze at a fraction below 32 degrees F., and that during cold eather Convict Creek sometimes ran for several days at 32 degrees or ss, with slight rises to 33 or 34 degrees in late afternoon.

The results of these tests are given in Table 4. At water temperatures ear 50 degrees F., catchable-size trout required approximately 12 to 16 ours to digest half-gram meals of the larger stream organisms. Diges- on at 35 degrees took roughly two to three times as long as at 50 de- rees, depending on the type of food, and complete digestion at a mperature barely above the freezing point took almost twice as long at 35 degrees. Half-gram meals of hard-bodied caddisfly larvae were igested in 70 hours at 32 to 33 degrees. Experiments with large meals ot tabulated) indicated that trout might feed to satiation in very ld water, but that digestive efficiency is impaired by overfeeding. For ample, fish that had gorged themselves on fresh trout eggs were able to digest their meals in 10 days at 32 to 38 degrees.

It is evident from Table 4 that the speed of digestion is controlled by ater temperature, and that the rate decreases sharply in the lower mperature range (below 35 degrees F.). It is possible that regular d moderately heavy feeding in cold water would result in the elimi-

TABLE 4

Results of Experimental Trout Feeding and Digestion Trials at Convict Creek, California, October 5, 1954, to February 28, 1955

Food organism (half-gram meal)	Hours for complete digestion in temperature range*			
	49-53	43-44	35-36	32-33
Helodrilus (soft-bodied)	12	18	25	—
Gammarus (intermediate)	13	18	26	43
Arctopsyche (hard-bodied)	16	24	44	70

* Expressed in degrees Fahrenheit.

nation of undigested food, as suggested by Leonard (1941). In the present trials with single meals, economical assimilation of food appeared to be a normal function in the coldest water. Digestion proceeded steadily though very slowly at 32 to 33 degrees, and examinations of fecal material disclosed that no undigested food organisms were eliminated.

Slow digestion at low temperatures would appear to have a balancing effect on the amount of nourishment taken in winter. Large meals, to be of value, would necessarily be infrequent, whereas small amounts of food could be accommodated almost continuously if available. The inference is that the ability of stream-dwelling trout to pass a cold winter in good nutritional condition is dependent not so much on an abundance of food as on a certain and not necessarily high level of steady food availability.

STARVATION EXPERIMENTS

To provide supplementary information on the importance of nourishment as a factor in seasonal trout survival, experiments were designed to test the vitality and viability of catchable-size trout under the most extreme condition possible: complete lack of food over extended periods. Four separate starvation trials were conducted, the nature of each succeeding one depending primarily on the suggestions of the last. These will be reported in order of occurence. Healthy trout within a size range of 5.5 to 8.0 inches, total length, were selected for all tests. Other than fungus on the extremities of a few individuals, no diseases or morbid conditions were experienced. To minimize disturbance and handling injuries, periodic measurements of body weight were avoided. The differences between initial and final values of the coefficient of condition (K), together with K values for trout at times of death, were used as indices of depreciation in body weight.

Winter, 1953-54

The first experiment began in December, 1953, and was terminated in April, 1954, after 120 days. Resident brown trout of normal early winter condition were used as subjects, since the purpose of this first test was to distinguish between mortality resulting from malnutrition following a normal autumn existence and winter mortality resulting from additional causes.

Two groups of trout were starved at the same water temperatures, the daily averages of which ranged from 32 to 41 degrees F. The control group was held indoors in hatchery troughs, while the other group was exposed to winter stream conditions in a food-tight outdoor enclosure. Degree of exposure was the only variable between the groups. Particulate food was excluded from the hatchery troughs by straining the supply water through a 40-meshes-per-inch screen at the intake and through layers of cheesecloth at the trough heads. Food organisms were excluded from the outdoor enclosure by applying layers of cheesecloth over the 4-meshes-per-inch hardware cloth walls and, later, over the cover. The indoor group was limited by available space to 100 fish (reduced to 97 by eliminating fungused, debilitated, or otherwise unsuitable individuals). The outdoor group, which comprised the remainder of the brown trout available at the time, was more than twice as large (266 fish, reduced to 254). Space per fish in relation to volume of flow was more than adequate for both groups of trout. Current in the outdoor enclosure was equalized with the slight current in the troughs by deepening the penned water and bypassing the surplus.

Neither group of trout was given any food in 120 days. Mortalities were recorded as they occurred, and are represented in a synopsis of the course of the test (Table 5). Nearly all mortalities in both groups occurred in the first two-thirds of the test period, which suggests that some of these wild fish were not in sufficiently good nutritional condition to withstand 2 to 3 months of fasting. Later tests (1954-55, 1955-56) demonstrated that many individuals of normal hardiness can live for at least seven months without food if the temperature remains low. Most of the 120-day survivors were active and in fair physical condition, which also suggests that the mortality attributable to lack of food resulted from a prior physiological weakness (shortage of reserve nutrients), aggravated by malnutrition. The depletion of reserve

TABLE 5

Mortality Record of Two Groups of Brown Trout Held Without Food in Exposed and Sheltered Situations at Convict Creek, California, December 10, 1953, to April 9, 1954

Days from entrance	Cumulative mortality of brown trout in:			
	Exposed group (254 fish)		Sheltered group (97 fish)	
	Number	Percentage	Number	Percentage
30	9	3.5		
45	18	7.1	1	1.0
60	22	8.7	4	4.1
75	42	16.5	9	9.3
90	42	16.5	9	9.3
105	44	17.3	9	9.3
120	45	17.7	9	9.3

nutrients in the absence of food has been shown by Phillips et al. (1953), who reported conspicuous reductions in the riboflavin, biotin, pantothenic acid, and fat content of trout livers as a result of 14 weeks of starvation.

Differential mortality between groups is most evident for the months of December, January, and February, the period of severe winter conditions. During this time the trout in the outdoor situation were subjected to as many of the natural vicissitudes of winter stream life as their enclosure would permit: the water was often filled with abrasive snow and slush or frazil ice; the flow was frequently reduced by upstream stoppages; and surface ice with an overburden of snow occasionally collapsed into the enclosure. Surface ice also formed in the indoor troughs, but did not constitute a danger to the occupants. At the conclusion of the test period the mortality in the exposed outdoor group was 17.7 percent and the mortality in the sheltered indoor group was 9.3 percent. The significantly higher percentage mortality in the stream group is offered as a positive indication that such observed hazards to winter survival as exposure to ice, slush, collapsing snowbanks, and fluctuating flow are of considerable influence in winter trout losses.

Fall, Winter, Spring, 1954-55

The second starvation experiment was conducted to determine (1) the losses that might be expected among catchable-size trout starved through the entire coldwater season, beginning in the fall, and (2) the ability of survivors to live and recover body condition when fed. In this test, 50 hatchery-reared rainbow trout and 60 resident brown trout were held in the food-free hatchery troughs for comparison of viability under starvation conditions. A local comparison of hatchery trout and wild trout necessarily involves these two species, which are commonly considered to compete with one another in streams. Brown trout populate nearly all streams of the area, whereas catchable-size rainbow trout are planted from the hatchery to meet heavy angling demands and are not available as wild stream fish.

Food was withheld from both groups until rainbow trout mortality had reached 50 percent and brown trout mortality had reached 61.7 percent, a period of 248 days or a little over eight months (October 15, 1954, to June 20, 1955). At this point, 23 survivors of each group were placed on a diet of amphipods (*Gammarus* sp.) to initiate the feeding phase. Moderate daily feeding was continued until termination of the experiment on September 15, at which time only three rainbow trout remained alive.

Early mortalities were few, possibly because trout of normal condition and healthy appearance were carefully selected for both groups. After 180 days of starvation, only five trout of each species had died. Beyond the six-month point, mortalities became more frequent and the death rate increased slowly (Table 6). Associated with the increased mortality was the steady spring rise of stream temperatures (Table 7). At seven months, 84 percent of the rainbow trout and 80 percent of the brown trout still survived. Comparable results were obtained in a similar experiment in Michigan (Adelman, Bingham, and Maatch, 1955), in which 90 percent of 5.5-inch brook trout and 75 percent of 7.5-inch brook trout survived seven months of starvation at 45 degrees F.

TABLE 6

Mortality Record of 50 Rainbow Trout and 60 Brown Trout Held Without Food at Convict Creek, California, October 15, 1954, to June 20, 1955

Days from entrance	Hatchery rainbow trout				Wild brown trout			
	Cumulative mortality		Mean condition factor (K)*		Cumulative mortality		Mean condition factor (K)*	
	Number	Percentage	Mortalities†	Survivors	Number	Percentage	Mortalities†	Survivors
0	--	--	--	0.940				0.793
60								
90	2	4.0	--	0.821				
120	4	8.0			1	1.7		
150	5	10.0			5	8.4		
180	5	10.0			5	8.4	0.628	
210	8	16.0	0.608		12	20.0	0.589	
230	11	22.0			21	35.0	0.600	
240	15	30.0	0.576		27	45.0	0.517	
245	21	42.0	0.543		32	53.3	0.574	
248	25	50.0		0.646	37	61.7		0.609

* Based on total length (tip of snout to end of caudal rays).

† Mortalities during period enclosed by braces.

TABLE 7

Summary of Air and Water Temperatures at Convict Creek, California, January, 1953, Through June, 1956

Month	Temperature in degrees Fahrenheit* (given in order under each heading are: mean monthly temperature, maximum temperature, and minimum temperature)							
	1953		1954		1955		1956	
	Air	Water	Air	Water	Air	Water	Air	Water
January	31.0	34.9	29.1	35.3	15.9	33.4	29.8	34.9
	52.0	41.5	58.0	38.0	40.0	37.0	52.5	40.0
	4.0	32.0	—2.0	32.0	—22.0	32.0	—18.0	32.0
February	31.3	35.4	22.9	34.8	24.3	34.8	25.2	35.0
	57.5	43.0	50.0	42.0	55.0	43.0	52.5	41.5
	5.0	32.0	—1.0	32.0	—2.0	32.0	—5.0	32.0
March	36.9	38.6	29.2	36.9	33.0	38.0	38.1	39.2
	66.0	49.5	54.0	46.0	63.5	49.5	71.0	51.5
	0.0	32.0	—5.0	32.0	2.5	32.0	4.5	32.5
April	42.8	43.3	45.8	45.4	39.0	41.0	42.7	46.3
	82.0	58.0	78.0	59.5	66.0	55.0	72.0	60.5
	3.5	32.0	11.0	32.0	10.0	32.0	9.5	33.5
May	44.5	45.9	55.6	51.3	†	47.3	50.2	52.5
	74.0	55.5	85.0	59.0	--	58.0	81.0	64.0
	16.5	18.5	37.0	37.0	--	34.5	20.0	41.5
June	54.6	50.9	57.5	53.4	--	53.0	59.0	57.6
	85.0	58.5	93.0	62.5	--	62.0	93.0	64.5
	21.0	41.0	19.0	41.0	--	43.0	28.0	49.0
July	64.2	58.5	62.7	60.1	--	58.6		
	88.0	65.0	88.0	69.0	87.5	70.0		
	31.5	50.0	36.5	51.0	37.5	49.0		
August	59.1	59.6	58.6	59.2	65.5	64.6		
	85.5	66.0	87.0	68.5	91.5	72.5		
	34.0	51.5	29.5	45.0	30.5	56.0		
September	56.2	57.3	54.6	55.5	57.5	59.6		
	81.5	65.0	82.0	66.0	91.5	71.5		
	26.5	49.5	26.0	45.0	22.0	49.0		
October	44.3	49.7	46.0	48.4	50.2	52.4		
	72.5	60.0	81.0	58.0	78.0	63.0		
	18.0	41.5	10.5	36.0	15.0	41.5		
November	37.5	42.4	37.3	42.9	39.9	42.6		
	66.0	50.5	64.5	49.5	77.5	55.0		
	7.0	33.5	—7.0	33.5	5.0	32.5		
December	31.2	36.3	22.3	35.6	33.8	37.7		
	62.0	45.0	46.5	41.0	63.5	46.0		
	—2.0	32.0	—12.5	32.0	—5.0	32.0		

* Compiled from recording thermometer hourly chart readings.

† Thermograph out for repairs.

In the last month of the starvation phase, maximum daily water mperatures ranged from 49 to 62 degrees F., and these higher temeratures undoubtedly produced unfavorably high metabolic rates in e weakened fish. After 248 days of total starvation, most survivors ere in such poor condition that their recovery seemed unlikely regardss of treatment. Coefficients of condition had dropped 31 percent for e rainbow trout and 21 percent for the brown trout, to averages of 646 and 0.609, respectively. Condition factors as low as 0.439 were oted among brown trout in June.

From November 1, 1954, to June 10, 1955, catchable-size rainbow out were confined in one of the quarter-mile experimental stream secons of Convict Creek, at the observed natural density of 120 pounds er acre, as one of several experiments to measure overwinter survival nd loss of condition among trout in the natural stream environment Nielson et al., 1957). Being from the same size-selected lot, these trout nd the rainbow trout held without food were initially identical and eir fates could therefore be compared for nearly all of the starvation eriod (222 out of 248 days). The stream-stocked trout could not be egarded as controls for the experimentally starved trout, as it could not e presumed that the trout in the stream were feeding regularly while he experimental group starved.

Aside from the nourishment factor, the stream-stocked trout were exosed to the natural snow and ice conditions previously shown to inuence winter mortality, while the starving trout were not. Nevertheess, it is revealing to compare the two groups as to mortality and loss f condition. After 222 days from the respective dates of entry (Noember 1 and October 15, 1954), the stream-stocked trout had suffered 6 percent mortality and the starving trout had suffered only 18 perent. The doubled mortality in the group that underwent natural stream ife is reminiscent of the results of the 1953-54 starvation trial with rown trout, and is again evidence that the physical stream conditions f winter constitute a potent factor in trout losses. The average condiion factor (K) of the stream-stocked trout declined 28 percent (0.939 o 0.673) in 222 days. When this is compared with the similar 31 perent loss in condition by the starving trout in 248 days, and when the oregoing differential survival in favor of starving trout is considered, t is evident that liberty in the stream and access to a limited food upply afforded no survival advantage to the stream-stocked trout during the winter period.

Beginning on June 21, natural food organisms (*Gammarus* sp.) were offered to 23 survivors of each species in quantities sufficient to provide one full meal per fish per day. Reactions of these emaciated rout to the sight of food were varied. Some fed so avidly as to suffer emporary losses of equilibrium, others fed sparingly, while still others remained in a lethargic state and took no notice of the food or the activity around them. The appearance of normal feces in the troughs within a few hours of the first feeding indicated that the digestive funcion had not been impaired by the long fasting period.

Data on mortality and condition of trout through the feeding phase are presented in Table 8. No radical changes in mortality rates were noted following the initiation of feeding, and no other evidence of injurious effects of unaccustomed food was observed. Brown trout main-

TABLE 8

Mortality Record of 23 Rainbow Trout and 23 Brown Trout Fed Natural Food * Daily Following a Starvation Period of 248 Days (Feeding Period: June 21, 1955, to September 15, 1955)

Days from entrance	Hatchery rainbow trout				Wild brown trout			
	Cumulative mortality		Mean condition factor (K)†		Cumulative mortality		Mean condition factor (K)†	
	Number	Percentage	Mortalities‡	Survivors	Number	Percentage	Mortalities‡	Survivors
0	--	--		0.646	--	--		0.609
10	5	21.7	0.621		4	17.4	0.572	
20	13	56.5	0.584		12	52.2	0.546	
30	14	60.9	0.538		20	87.0	0.587	
40	17	73.9	0.778		21	91.3		
50	19	82.6	0.480		23	100.0		
60	19	82.6						
70	19	82.6						
80	19	82.6						
86	20	87.0	--	0.808				

* Amphipods (Gammarus sp.).

† Based on total length (tip of snout to end of caudal rays).

‡ Mortalities during period enclosed by braces.

tained about the same average body condition as when first fed, but all died within 50 days. Of the rainbow trout for which accurate condition factor data could be obtained at time of death, most declined gradually from an average condition factor of 0.646 for the first 50 days of feeding. The four rainbow trout surviving at 50 days gradually improved in condition and took on a more healthy appearance. After 86 days of feeding, the average coefficient of condition of these survivors was 0.808.

The first six months of the 1954-55 starvation trial included the entire coldwater season as indicated by air and water temperatures (Table 7). At the end of six months, mortality was still so light that serious loss due to malnutrition probably could have been avoided by feeding. In view of the high mortality rate experienced in the last part of the starvation phase (230 to 248 days, Table 6), and in the early part of the feeding phase (Table 8), it is considered that feeding began too late to result in a fair test of the ability of starved trout to recover with the aid of nourishment.

Summer, Fall, Winter, 1955

The main purpose of this trial was to discover the effect of summer and fall stream temperatures on mortality among starving trout, it having been observed in the previous trial that mortality rates rose with the late spring rise in water temperatures. A secondary purpose was to observe mortality among survivors of these summer-starved trout during the following period (November to December), when stream temperatures fall to winter levels.

One hundred hatchery rainbow trout (in duplicate groups of 50 each) and 50 wild brown trout were starved in the cheesecloth covered outdoor pens, built into one of the concrete water-control structures in the stream, beginning on July 1, 1955. Complete screening of the enclosures was necessary at this season to prevent ingress of aerial as well as aquatic food forms. The experiment was terminated on January 4, 1956, (187 days), at which time snow and stream ice threatened the shelter.

Daily records indicated that the first 120 days of the experiment were characterized by minimum stream temperatures above 40 degrees F. and that the first minimum below 40 degrees occurred on November 2 (123 days). Stream temperatures then continued to decline in November and December, as indicated by the monthly averages (Table 7). Since the 40-degree level appeared to be near a natural temperature division between seasons both in spring and in fall (Table 7), the first four months of starvation were regarded as a period that represented summer-fall temperature conditions. The mortality and condition records of the three lots of trout starved through this period may be reviewed in Table 9 (0 to 120 days). Most striking was the early onset of heavy mortality among the brown trout. Within 60 days of entry 32 percent of the brown trout had died, whereas neither group of rainbow trout had suffered any mortality. At 90 days, brown trout mortality had reached 56 percent and only one rainbow trout had died. At the 120-day point no further rainbow trout mortality had occurred, but brown trout losses stood at 82 percent.

Survival of brown trout was markedly improved in the fall and early winter (120 to 187 days, Table 9). Mortality during this period

TABLE 9

Mortality Record of 100 Rainbow Trout (in Two Groups of 50 Each) and 50 Brown Trout Held Without Food at Convict Creek, California, July 1, 1955, to January 4, 1956

Days from entrance	Hatchery rainbow trout—group A				Hatchery rainbow trout—group B				Wild brown trout			
	Cumulative mortality		Mean condition factor (K)*		Cumulative mortality		Mean condition factor (K)*		Cumulative mortality		Mean condition factor (K)*	
	Number	Percentage	Mortalities †	Survivors	Number	Percentage	Mortalities †	Survivors	Number	Percentage	Mortalities †	Survivors
0	--	--	--	1.068				1.068				0.808
30												
45									7	14	0.540	
60									16	32		
75	--	--	--	--	--	--	0.686		19	38	0.494	
90					1	2			28	56	0.513	
105					1	2			34	68	0.551	
120‡	--	--	0.567	0.789	1	2	0.606		41	82	0.555	0.649
150	6	12	0.591		3	6	0.702		43	86	0.556	
180	13	26	0.616		10	20	0.637		46	92		
187	14	28		0.725	13	26		0.719	46	92	--	0.559

* Based on total length (tip of snout to end of caudal rays).
† Mortalities during period enclosed by braces.
‡ Dividing line between summer-fall and winter starvation periods.

amounted to only 10 percent of the initial number of trout, whereas losses amounting to 50 percent had occurred in an equivalent earlier period (60 to 120 days). Although the number of fish remaining was too small to permit any definite conclusions, such an improvement in survival rate appears to reflect a downward adjustment in metabolism as effected by the seasonal decline of stream temperature. An alternative view, that the few surviving brown trout were possibly the hardiest individuals in the original lot and were therefore able to resist starvation longer, is contradicted to some extent by the extremely low average condition factor (0.559) of four survivors at the end of the experiment. The majority of brown trout had perished earlier, at approximately the same level of condition.

The rainbow trout entered the experiment in relatively good body condition and evidently did not become critically wasted during the first four months, even though their loss of condition was more rapid in this time than in the final weeks of the experiment. The beginning of a definite mortality pattern in both groups of rainbow trout followed closely after the 120-day point (Table 9). Any favorable effects of cold-hardening on the viability of the starving rainbow trout were largely obscured by this mortality, which was probably due more to the accumulation of ill effects with time than to changes in the environment.

It is certain that summer water temperatures, which ranged up to 72.5 degrees in August, accelerated catabolic processes leading to early and severe malnutrition in the brown trout. Weight loss as indicated by reduction of average coefficient of condition (K) was even more pronounced in rainbow trout (1.068 to 0.789 = 26 percent loss) than in brown trout (0.808 to 0.649 = 20 percent loss), but the loss of condition in the first 120 days obviously did not reduce the average hatchery rainbow trout to the point of imminent death. The average condition of the rainbow trout after 120 days of starvation was not markedly lower than the average initial condition of the wild brown trout. The lower-than-average condition factors of brown trout that died during this period are also significant (Table 9). Evidently, the less robust members of the group were more quickly susceptible to the effects of summer starvation.

In considering the effects of temperature on reduction of body condition it is pertinent to compare the above percentages with those experienced in the previous 248-day starvation trial (rainbow trout: 31 percent reduction; brown trout: 21 percent reduction). In terms of temperature units[3] used as summations of heat (Reimers and Combs, 1956), the 248-day period was characterized by a water temperature total that was only 61 percent of that of the 120-day summer-fall period (1,952 and 3,166 temperature units). In one-half the time, but associated with over one-and-a-half times as many thermal units, there was approximately the same percentage loss of body condition in the trout starved through summer and fall as in the trout starved through fall, winter, and spring.

It is suggested that the ability of a trout to endure withdrawal of food for any reason (e.g., seasonal food scarcity; isolation from normal habitat; aestival inertia; suspension of feeding while adjusting to new habitat) is dependent more on its body condition at the time than on its origin. A reserve of body tissue and essential nutrients is a definite asset to the trout that must withstand a fasting period. In the present test, hatchery rainbow trout in their initial season of natural surroundings demonstrated summer vitality superior to that of wild brown trout in a stream situation that has generally been thought to favor wild or resident trout.

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[3] Degrees F. per day in excess of 32 degrees.

Fall, Winter, Spring, 1955-56

In the previous long-term starvation trial (1954-55) it was found that an amazingly large percentage of trout could exist without food for six or seven months, through the colder seasons, in a situation uncomplicated by severe winter stream conditions. Indications were that continued lack of food at higher temperatures resulted in excessive mortality and loss of the capacity to recover weight and strength when food was again made available.

In the present experiment trout were held 180 days without food during a period that corresponded to the first six months of the previous overwinter trial (October to April), and survivors were then fed to observe recovery. The 180-day point (April 12, 1956) occurred at a time when stream food availability would normally begin to increase after the winter season. In this regard, the test of ability to recover from a starved condition was initiated at the normal seasonal point, with respect to rising water temperature and the resumption of regular feeding by trout in the stream.

As in the previous overwinter starvation test, survival through 180 days was excellent (rainbow trout: 98 percent; brown trout: 92 percent). From the standpoint of body condition the hatchery rainbow trout did not reach a starved or emaciated state, but the wild brown trout were thin and weak as the result of a 19.7 percent reduction in coefficient of condition (Table 10).

Feeding began with live food (*Gammarus* sp.), but a shortage of these organisms dictated the use of a regular hatchery diet after two weeks. Daily feeding of surviving brown trout and one group of surviving rainbow trout continued for 56 days, after which time it was apparent that a recovery had been made. Rainbow trout gained slightly in body condition (+ 1.0 percent) during the feeding period. Brown trout improved markedly in condition (+ 10.2 percent), presumably because of an excess of food in relation to average body weight. Both groups improved in general appearance, and in vitality as indicated by increased activity and stamina. One feeding rainbow trout and three feeding brown trout died during the 56 days.

The second group of rainbow trout, which had continued to starve as a control, lost only one member but reduced drastically in body condition (— 17.0 percent) during the feeding phase. This group lost 32.6 percent of initial body condition over the entire 236 days of starvation.

In conjunction with the starvation trial, 100 catchable-size rainbow trout were held in a pool adjacent to the creek for an approximately corresponding six-month period (November 3, 1955, to April 30, 1956). The purpose of this test was to determine overwinter survival of the trout in a situation where food was available in some slight degree but where current did not demand normal stream activity of the subjects and where ice action did not create conditions detrimental to survival.

TABLE 10

Mortality and Condition of 100 Rainbow Trout (in Two Groups of 50 Each) and 50 Brown Trout Held at Convict Creek, California, October 14, 1955, to April 12, 1956 (Without Food) and April 12, 1956, to June 7, 1956 (Brown Trout and Group-A Rainbow Trout Fed Daily)

Days from entrance	Hatchery rainbow trout—group A				Hatchery rainbow trout—group B				Wild brown trout			
	Cumulative mortality		Mean condition factor (K)*		Cumulative mortality		Mean condition factor (K)*		Cumulative mortality		Mean condition factor (K)*	
	Number	Percentage	Mortalities †	Survivors	Number	Percentage	Mortalities †	Survivors	Number	Percentage	Mortalities †	Survivors
0	--	--	--	1.135				1.136				0.852
30									--	--	0.833	
45									2	4		
60					1	2			3	6	0.848	
120	--	--	1.135		1	2			3	6	0.720	
150	1	2			1	2			3	6		
180‡	1	2	--	0.900	1	2	--	0.924	4	8	--	0.684
210	1	2	1.004		1	2			7	14	0.643	
236	2	4		0.909	2	4	--	0.765	7	14	--	0.754

* Based on total length (tip of snout to end of caudal rays).
† Mortalities during period enclosed by braces.
‡ Began daily feeding of survivors (rainbow trout Group A, and brown trout).

The pond was roughly 1,200 square feet in surface area and had a mean depth of about one-and-one-half feet when filled. Water level and circulation were maintained through screened channels connected with a primary stream section. The pond had been maintained for several years, with occasional temporary occupation by trout, and it could be assumed that a small supply of natural food was in existence at the time of the trial reported here. Although surface ice with a cover of snow was present on the pond for at least half of the six-month period, its only discernible effect on the habitat was to reduce light.

After the light losses experienced in two six-month starvation tests of these rainbow trout it came as no great surprise, on draining the pond at the end of April, to learn that all 100 fish had survived. The average condition factor declined 22 percent (1.091 to 0.855) during the test period. By comparison, loss of body condition among rainbow trout in the concurrent starvation trial averaged 20 percent. It will be recalled that rainbow trout stocked in the natural stream sections the previous November (1954) suffered 36 percent mortality and lost 28 percent of their body condition in 222 days. Rainbow trout similarly stocked in November, 1955, suffered only 11 percent motality but lost 32 percent of their body condition in 218 days.

This combination of tests provides further evidence that food is not a critical factor in overwinter survival of trout in sheltered water of the area studied. Loss of body condition through the coldwater season was similar in sheltered groups of trout, whether starved or exposed to a minimum food supply, but was somewhat greater in the stream, where food was also available in minimum quantities. Survival of starved trout was far greater than that of trout at liberty in the stream. The importance of snow, ice, current, and exposure conditions as mortality agents in the stream is emphasized by the comparison of survival rates between groups of trout held in pond (lentic) and open stream (lotic) situations.

TROUT SURVIVAL IN RELATION TO FOOD AND EXPOSURE

As pointed out by Hazzard (1941), the severity of weather and ice conditions determines the damage that may be done to stream bottom food supplies by the loosening, scouring, and molar actions of anchor ice, accelerated current, and solid ice. Although the findings are somewhat in conflict, it appears that the amount of damage from anchor ice may be less in larger streams. Anchor ice was observed to serve as a means for downstream dispersal of bottom organisms in the Pigeon River, Michigan, but depletion and physical damage to the stream bed were considered negligible (Benson, 1955). O'Donnell and Churchill (1954) described extensive scouring and movement of bottom materials as a result of frequent anchor ice dam releases in the Brule River, Wisconsin. On the basis of sampling over several weeks they reported 4,440 to 16,560 (average of 9,480) aquatic organisms per hour being carried past a given point by released anchor ice, and they concluded that the total disturbance to the bottom environment could reach such proportions as to be a limiting factor to the trout populations. A study of the effects of ice in the West Gallatin River, Montana (Brown, Clothier, and Alvord, 1953), disclosed little or no depletion of bottom fauna by anchor ice, although masses of freed anchor ice were observed to dislodge and transport organisms. These authors found, however, that freezing of the stream bottom near the shore annihilated the organisms present.

Small streams of moderate to steep gradient, with many riffle areas, are more susceptible to depletion in prolonged cold weather because of greater exposure of sections of the bottom to freezing and sudden scouring in anchor ice cycles. Damage to the bottom and banks of Convict Creek by increased flow and anchor ice release occurred in early 1951. Long-term blanketing of stream areas by snow and ice cover rendered the stream bottom almost sterile in the early spring months of 1952. Anchor ice repeatedly disturbed bottom areas, dislodged organisms, and subjected riffle sections to partial drying and freezing in early 1953. Midwinter food intake by stream-resident trout was so low as to suggest very low availability of the food organisms that were present.

The winter stream conditions described for Convict Creek are common to many small trout streams in the alpine west and in other localities of similar climate, and the bottom food crops of such streams must be similarly depleted or unavailable to trout in winter and early spring. However, it is obvious from the results of tests described in foregoing sections that scarcity of food during winter months cannot by itself be a limiting factor in the survival of trout in any single year. Although an abundance of stream food is undoubtedly an important asset to the growth and success of a trout population, it seems clear that the impact of seasonal food scarcity on survival rates for a given winter is felt only when the physical conditions of the environment are barely tolerable to trout. Trout that must maintain normal stream activity during a season of relative famine, when their energy output should be low, must suffer from starvation in proportion to the rigors of the environment. In a single winter, the effect of food shortage alone is indicated as temporary debility, not mortality, for a large majority of the trout.

It was demonstrated in the starvation experiments that the ability to fast is an adaptation that serves to assist the fish through a difficult season in terms of food, but it was also made clear that the results of tests in sheltered situations cannot be applied directly as expectations for the exposed winter stream. Scarcity of food, unavailability of food, and inability to assimilate normal quantities of food must therefore be listed as contributory in some degree to winter trout mortality in swift streams that are exposed to rigorous winters. Physical deterioration of the habitat is indicated as the primary agent of winter mortality in such streams. The most important single cause of death is probably suffocation, following exhaustion, as a result of one or more forms of exposure.

In view of the present findings on coldwater digestion and the ability of healthy trout to withstand several months of fasting, the question of the importance of winter food to trout survival may be approached with the quality and vitality of the trout, rather than the quality of the food supply, as the main point of reference. In starvation trials in all seasons. well-nourished hatchery rainbow trout demonstrated better survival qualities than did stream-conditioned wild brown trout. The results of the feeding phase of the final starvation experiment indicated that overwinter fasting or partial fasting should not be harmful to the majority of catchable-size trout in sheltered situations, provided that the spring rise in water temperature is accompanied by an increase in the food supply. Clearly, superior body condition and a supply of reserve nutrients were advantageous to the hatchery trout in these experiments. It is logical to assume that the excess weight which results from forced growth in the rearing of most stocked trout is beneficial to survival through the first year, particularly in small streams that are incapable of providing sufficient food for hatchery trout superimposed on wild trout populations.

The excellent survival of hatchery trout in starvation periods of four months during summer and fall (99 percent) and six months overwinter (average of 95 percent for three groups of fish in two tests) raises the question of the importance of competition for food among these trout, and between them and trout that are established in the streams that are stocked. Information on the effect of competition may be drawn from the data of six years of survival experiments at Convict Creek (Nielson et al., 1957). No convincing evidence of decreased annual survival as a result of increased trout density was found at stocking rates from 50 to 250 pounds of trout per acre, although with this much variation in fish density it must be assumed that the available food per fish also varied radically. The above applied to both hatchery rainbow trout and wild brown trout. Within the same group of experiments, rainbow trout held in an isolated section of the stream for 27 months incurred no survival benefits during the second year as a result of decreased density and wider foraging opportunity following the first year's mortality. Survival in the second discrete year (12.1 percent) was much lower than in the first (66.5 percent), presumably because of increased age and/or differential exposure between years.

The main purpose of stocking catchable-size trout in streams is to alleviate angling pressure in the season of planting or in the season that follows fall stocking. Since the present ideal in the management of such stocking programs is a complete harvest within the year, the problem of intraspecific food competition among the hatchery trout during the expected period of usefulness would appear to be a small one in terms of quantitative survival. Similarly, food consumption by resident trout would have little to do with survival of superimposed catchable trout in the year of stocking. It is possible that put-and-take stocking far in excess of carrying capacity, as understood in terms of natural food production, may be practiced repeatedly without significant nutritional mortality of hatchery trout prior to capture. However, the lower vitality of stream-conditioned wild trout in the absence of summer food, demonstrated in the 1955 starvation trial, indicates that such stocking practices may have sufficient effect on the food fauna of a small stream to limit the success of the resident trout.

SUMMARY

During the period April, 1952, to June, 1956, when suitable conditions prevailed, experiments and observations bearing on the general problems of winter trout food availability, trout vitality, and trout survival as related to food were conducted at Convict Creek Experi-

ment Station, Mono County, California. This U. S. Fish and Wildlife Service fishery research unit is located at an elevation of 7,200 feet on Convict Creek, a small stream on the eastern slope of the Sierra Nevada.

Stream bottom sampling immediately after the dissipation of prolonged ice and snow cover in April, 1952, demonstrated that a severe winter in this area reduces the bottom fauna of a swift stream drastically below the normal winter condition, to a point where the intake of food by trout must be limited. Analysis of the stomach contents of 66 trout taken from the stream in February, 1953, indicated an extremely low intake of food in a critical winter month. Sampling indicated that drift foods are more abundant relative to the bottom food supply in February and March, when ice action prevails, than later in the spring, but the food analysis demonstrated that lack of feeding selectivity reduces any advantage the trout might gain from such increases in drift foods.

The question of the digestive efficiency of rainbow trout at various water temperatures was explored through controlled feeding of soft-bodied, intermediate, and hard-bodied natural food organisms. Digestion was found to proceed slowly but steadily at temperatures closely approaching the freezing point. Time required for complete digestion of half-gram meals ranged from 12 hours for the soft-bodied food organisms at 49 to 53 degrees F. to 70 hours for hard-bodied insects at 32 to 33 degrees F. From results of the low temperature digestion trials it may be deduced that the amount of nourishment trout can obtain from available food in extremely cold water is controlled primarily by the rate of assimilation, so that the low food supply associated with severe winter stream conditions cannot by itself be regarded as a crucial factor in trout survival.

Trials to determine the effects of prolonged starvation were conducted with several lots of trout at various times, and results indicated that survival without food is favored by low water temperature and high initial condition of the fish. Higher mortality (17.7 percent) among trout starved for 120 days in an outdoor stream enclosure than among those of a control group starved indoors at the same low water temperatures (9.3 percent) emphasized the importance of such physical factors as abrasion by slush and ice, collapse of snow and ice bridges and snowbanks, and fluctuating flow (with stranding and restrictions on movement) in winter trout survival.

Groups of hatchery rainbow trout and wild brown trout were held without food for a total of 248 days through fall, winter, and spring months with mortalities of 50 and 62 percent. Only slight recovery was made among survivors fed natural food. Summer-fall starvation trials resulted in decimation of wild brown trout (82 percent mortality in 120 days), but negligible loss of super-nourished hatchery rainbow trout (2 percent mortality in 120 days). Disease was not a factor in the mortalities. In a fourth experiment, mortality after 180 days of overwinter starvation was 2 percent among hatchery rainbow trout and 8 percent among wild brown trout. Feeding initiated at 180 days revitalized and improved the body condition of both species, and mortality rates remained low through 56 days of feeding. In an associated experiment, 100 percent overwinter survival of hatchery rainbow trout was obtained in a small pond that provided a little natural food and a sheltered habitat. Survival of rainbow trout held in the open stream for comparable periods ranged from 64 to 89 percent.

The results of the starvation trials point to the following conclusions: (1) healthy trout are adapted to and are capable of long periods of fasting, particularly in cold water; (2) planted trout need not make immediate heavy demands on the environment; and (3) competition for stream foods among catchable-size planted trout, or competition between these and resident wild trout, may be largely disregarded as a critical factor in survival of planted trout to the creel of the year. Present data also support the more general conclusion that overwinter losses of catchable-size trout in small streams exposed to severe winter conditions result primarily from adverse and exhaustive physical conditions in the stream, and that food is a secondary and qualitative factor in survival.

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A BIBLIOGRAPHY OF THE HERRING

(*CLUPEA HARENGUS* AND *C. PALLASII*)

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Leslie W. Scattergood
U. S. Fish and Wildlife Service

(This paper is one of several reports resulting from the herring investigation carried on jointly by the U. S. Fish and Wildlife Service, the Maine Department of Sea and Shore Fisheries, and the Maine Sardine Industry).

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The common herring of the North Atlantic (*Clupea harengus*) and, to lesser extent, the closely related species of the North Pacific (*C. pallasii*) have bee studied intensively by fishery investigators of many nations; consequently, a formi able mass of literature has developed. Articles dealing with herring appear in man languages and numerous publications, such as books, journals, and reports. Thes publications are scattered throughout many libraries.

When the present Atlantic herring investigation began in 1947, under cooperative agreement with the Maine Sardine Packers Association, Maine Depar ment of Sea and Shore Fisheries, and the U. S. Fish and Wildlife Service, it wa recognized that knowledge of the results of previous herring investigations woul be valuable, and work was begun on compiling a bibliography. This report contain the herring references that have been collected since 1947. Much of this work wa accomplished while the compiler had a Fulbright grant in Norway.

Annotation of this bibliography is not now possible, for not all the publication appearing in languages other than English have been read. Eventually, an annotation may be provided; many of the more important publications have already been translated.

As with most bibliographies, the compiler assumes the responsibility for deciding which publications should be included. It is not unlikely that his decisions will be questioned in regard to listing some references while omitting others. In the preparation of this bibliography, particular efforts have been made to obtain references dealing with the herring of the northwestern Atlantic, and, consequently, the literature concerning the *C. harengus* of the eastern coasts of Canada and the United States is more complete than for other regions. There are some publications, especially ones of Russian origin, that the compiler was unable to locate; they are not included herein.

This bibliography deals primarily with the biology of the herring. Technological reports, concerning methods of catching, processing, or marketing, are not listed, unless they are involved somehow with biology. No special attempt has been made to secure references more than 100 years old, but most of the important publications of that age or greater are included.

A report of this type is not possible without the cooperation of many institutions and individuals. Particularly useful were the following: Central Library of the U. S. Department of the Interior, Washington, D. C.; Museum of Comparative Zoology Library, Cambridge, Massachusetts; Marine Biological Library, Woods Hole, Massachusetts; Fiskeridirektoratets Bibliotek, Bergen, Norway; and Atlantic Biological Station Library, St. Andrews, N. B., Canada. A great many other libraries loaned material.

Several individuals were particularly helpful. Paul T. Macy checked many of the references and offered numerous suggestions to improve the bibliographic arrangement. W. G. VanCampen provided a translation to "A bibliography of herring" by Sigeru Motoda and Isamu Takeuchi. George A. Rounsefell loaned a Pacific herring bibliography that he had prepared several decades ago.

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COMMITTEE ON COMMERCIAL FISHERIES

Leslie W. Scattergood

This report of the Commercial Fisheries Committee has a two-fold purpose. First, as in past years, it presents information on the production, trends and developments of the more important North American commercial fisheries for the year 1955. Second, it offers a few thoughts and questions concerning the future of the fisheries and the need and possibilities for increased production in the decades ahead.

The members of this committee have assisted in providing information on the fisheries with which they were most familiar, and Mr. W. C. MacKenzie, Director of the Market and Economics Service of the Canadian Department of Fisheries, kindly furnished a review of the 1955 fisheries of his country. Their help is sincerely acknowledged.

Commercial Fisheries of United States and Alaska

The commercial fishermen of the United States and Alaska caught in 1955 an estimated 4.6 billion pounds of fish and shellfish valued at 325 million dollars.[1] Compared with the previous year, this was a drop of about

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[1] The statistical information concerning the 1955 fisheries has not yet been completely compiled for all species. No data are now available for fresh-water fisheries. Estimates are used for the total United States figures; the data on the landings of the principal species are available so that the possible error in the estimated total is low.

45 million pounds and 35 million dollars. This difference is the net result of some gains and some losses, rather than a uniform decrease throughout the industry.

On the Pacific coast, including Alaska, the principal production is of tuna, salmon, sardines, herring, and halibut. The tuna industry continued to suffer severe setbacks during 1955, and the catch fell 18 percent from the previous year. Increased imports of canned and frozen tuna, wage disagreements; and large carry-over stocks marked the West coast tuna industry in 1955, and the catch declined to 264 million pounds. The Pacific salmon fishery dropped alarmingly, and the catch of these species in the United States and Alaska fell to about 286 million pounds, which resulted in the smallest pack of canned salmon since 1906 when the industry was young. Pacific sardines, once the object of a tremendous fishery that captured annually up to 1.5 billion pounds, yielded 143 million pounds, which represented only a slight improvement over the 1954 catch. Factors tending to reduce the production of this species were the continuing scarcity of the fish and delays in opening the season caused by strikes of cannery workers. Had fishing started earlier, the catch would probably have been slightly higher. Alaska herring catches were 63 million pounds, which was almost twice that of 1954, but still below what is considered as a good year. Pacific halibut landings declined from the previous year, and a big factor contributing to this drop was the poor weather during the final week of the legal season. The catch of 59 million pounds, however, was still above the average for the past four decades. Jack mackerel landings doubled in California, but the catch of 35 million pounds in 1955 was only one-quarter of that in the peak year of 1952. Pacific mackerel production continued to decline, and 21 million pounds were caught.

On the Atlantic coast, including the Gulf states, the most important feature was the continued increase of the menhaden fishery. The 1955 catch was 1.8 billion pounds, thus exceeding the previous year's catch by 50 million pounds and establishing a new production record for a United States species of fish. Another great fishery is for shrimp whose catch was about 250 million pounds, representing a decrease of about 15 million pounds from the 1954 total. This decline was attributed partially to inclement weather conditions in the major producting areas. Complete data are not now available for the trash or "industrial" fishery that captures a variety of low-priced species on all coasts of the United States for reduction or animal food, but there was undoubtedly an increase; for example, the fishery for trash fish, exclusive of menhaden, in New England increased 13 millions to a total of 127 million pounds. In contrast, landings of most of the principal species of groundfish and ocean perch (redfish or rose fish), which support the New England fillet industry, dropped markedly in 1955. Haddock fell from 155 million pounds to 136 million pounds, and the total cod catch of 35 million pounds represented a one million-pound decline. Ocean perch receipts slipped from a production of 181 million pounds in 1954 to 157 million pounds in 1955 as the fishermen continued to seek more distant and profitable grounds. Of the other important Atlantic fisheries, whiting catches rose 20 million pounds to a total of 114 million pounds, and pollock were up four million for a total of 24 million pounds. It is of interest to note that landings of ocean perch and whiting, whose combined 1955 totals were almost 150 thousand tons, are about 30 times greater than those of 25 years ago, when both species were largely ignored. The production of lobsters and sea scallops was near record highs. Maine herring catches declined 24 million pounds from the previous year, and this was largely caused by a shortage of the immature fish that are used as sardines. The fish stick industry continued to expand, and a new record of 65 million pounds was established. This was an increase of 31 percent over 1954. Both domestic and imported groundfish are used as fish sticks.

Imports and exports are important features of the United States fishery economy. Tuna and groundfish imports are of particular interest to the domestic industry. Frozen tuna imports increased to 145 million pounds and canned tuna in brine to 35 million pounds, a total gain of about 26 million pounds. The tuna imports were mainly from Japan and Peru and competed with both domestic fishermen and canners. Imports of groundfish, including those from cod, haddock, hake, pollock, cusk and ocean perch, declined nine million pounds from the previous year and totaled 129 million pounds. Canada supplied about three-quarters of this amount; Iceland, Norway, Denmark, and West Germany were also important suppliers. Imports of shellfish continued to increase, as fisheries for these crustaceans were further developed in other countries. Frozen shrimp imports, principally from Mexico, Panama, and Ecuador, increased 13 million pounds to a total of 54 million pounds in 1955. Frozen lobster and crawfish imports rose three million pounds to the 45-million pound total in 1955. Canada supplied about half of these imports, with the Union of South Africa, Australia, Cuba, and New Zealand contributing most of the remainder.

In view of the American Fisheries Society's interest in fish culture, it is appropriate to discuss trout farming, a commercial fishery activity that is not particularly well known. Mr. Charles R. Foster, a member of this committee, is responsible for the information that is given here. There are estimated to be between 500 and 600 privately owned trout farms in the United States, and their 1955 output is estimated at four million pounds of fish. About half of this total is sold as live fish to state agencies for stocking public waters, or to individuals for planting privately owned waters. The other half is marketed as dressed fish for domestic consumption and competes in the United States market with imports of fresh and frozen trouts, principally from Canada, Denmark, and Japan. Trout imports totaled over four million pounds in 1955.

United States fishery exports are primarily inedible fish oil and canned fish, including sardines, salmon, squid and mackerel. The inedible fish oil amounted to 142 million pounds, only about two million more than the previous year. Of this amount, the Netherlands took more than half and Canada and West Germany together imported a little less than one-third. The Philippine Republic purchased about three-quarters of the canned sardines, not in oil, but in tomato or mustard sauces, that were exported. Other large buyers of the 42 million pounds of these canned sardines were Cuba, Belgium, and Ecuador. These 1955 exports greatly exceed the previous year's total of 16 million pounds. Canned salmon exports also increased over 1954, for the shipments in 1955 were ten million pounds and in 1954 about seven million. The United Kingdom took almost half the 1955 exports, and Canada about one-third. Another important canned product is canned squid, and exports of this item more than doubled in 1955; of the 15 million pounds shipped from the United States in 1955, about 85 percent went to the Philippine Republic.

The most important piece of fisheries legislation to be enacted during recent years was the Saltonstall-Kennedy Act of July 1, 1954. This Act made available to the United States Department of Interior about $3 000,000 annually for a period of three years to "promote the free flow of domestically produced fishery products in commerce by conducting a fishery educational service and fishery, technological, biological and related research programs . . . and to develop increased markets for fishery products of domestic origin and to conduct any biological, technological or other research pertaining to American fisheries."

The Fish and Wildlife Service is the primary research agency for the implementation of the Act, and, consequently, a great expansion of activities and personnel has resulted. The Department of the Interior has adopted the policy that qualified research agencies outside the Fish and Wildlife Service should be given the opportunity, wherever possible, to broaden their own fishery research potentialities by being offered contracts to conduct needed studies in their particular fields. This policy has limited the need for an increase in the Fish and Wildlife Service staff to those projects it is best qualified to study, and it permits the Service to devote its major efforts to the particular fields in which a centralized research agency can operate most effectively. In addition, this policy has placed most problems in the hands of those people best able to solve them either by reason of experienced staff, specialized facilities, or extensive regional knowledge of the subjects. In many cases, it is stimulating local fishery research centers to such a degree that the industry in the not-too-distant future will be able to call upon a much wider choice of capable consultants in many fishery problems. In carrying out this policy, the Department let about 60 contracts in every section of the country for over 40 percent of the funds available for the fiscal year 1955. Contracts were given to 30 universities, colleges, and public institutions, and 13 commercial and independent scientific research organizations. The Department intends to continue this practice.

Prior to the Saltonstall-Kennedy Act, the Fish and Wildlife Service had been conducting research on the principal commercial fishery problems, both biological and technological. The Act has enabled these main problems to be pursued more vigorously and has also permitted the study of new problems. The biology of the most important commercial species is now being studied intensively, and a great deal of effort is being spent on the exploration, development, and utilization of the fishery resources.

COMMERCIAL FISHERIES OF CANADA

The marine fisheries of Canada yielded in 1955 a total catch of 1.7 billion pounds valued at 75 million dollars. Compared to 1954, this was a decrease of 200 million pounds and eight million dollars. Information on the fresh-water fisheries is not yet available.

In 1955 production of the Pacific area's principal species, salmon, halibut, and herring, fell considerably below the previous year's levels as a result of various circumstances. Catches of sockeye salmon were disappointingly low, as were those of the chum salmon. A record pack of pink salmon was a somewhat compensating factor. Total salmon landings were 50 million pounds less than in 1954, and the total landings were only 129 million pounds in 1955. Catches of herring were some 55 million pounds lower than in the previous year, the decreased production being the result of two principal factors. First, the 1954-55 winter herring season ended in February, a month earlier than usual, when new bodies of fish failed to appear; and, second, there was a price dispute between fishermen and reduction plant operators which discouraged summer fishing and delayed the 1955-56 winter season. The 1955 herring catch was 305 million pounds, representing a decrease of 56 millions. The 1955 halibut fishery produced 20 million pounds, which is five million less than in 1954.

The Atlantic coast fisheries yielded 1.3 billion pounds in 1955, about 66 millions less than in 1954. The catch was, however, about the same in weight and value as that of 1953, which may be considered average year. A large decline was that of the cod fishery, which landed about 97 million pounds less than in 1954. This decrease was due almost entirely to the disappointing trap fishery in Newfoundland. The most valuable species is the lobster, whose 1955 catch of 49 millions was the largest since 1932 and had a record value.

Production of fresh and frozen groundfish increased in 1955, and this increase was associated with a greater diversion of cod and haddock to production of frozen fillet blocks for the expanding fish stick industry in the United States. Haddock landings rose significantly in Nova Scotia and Newfoundland, and the total catch was 134 million pounds, an increase of 16 million over 1954. Ocean perch declined about ten percent to 43 million pounds, and mackerel dropped at approximately the same rate to 27 million pounds. The yields of pollock, hake, and cusk increased four millions to 57 million pounds, and flat fish landings rose about 30 million to 83 million pounds. The herring fishery was about ten million pounds greater than in 1955, but the catch of small herring in New Brunswick was poor, causing local shortages of bait and a decreased sardine pack.

Canada consumes only about one-third of its fishery products; the other two-thirds are exported, principally to the United States, which received about 70 percent of the Canadian exports. Frozen groundfish fillets, live lobster, herring oil and meal, salt cod, and cured herring are the principal exports to the United States. Exports of salt cod from both Newfoundland and the mainland compares favorably with those of 1954, with Caribbean markets showing particular strength.

FUTURE OF COMMERCIAL FISHERIES

According to the estimates of the demographers, the world population is increasing at such a rate that in a century the number of people will be at least twice the present 2.6 billion. It is even possible that the population in the year 2050 may reach 10 or even 15 billion. A less than two-fold increase could result only from a catastrophe.

North America now has ample food for its own needs, but most of the world has difficulty in providing sustenance for its growing population. It is generally acknowledged that more than one-half of the present world population is subsisting on a near starvation diet and another one-fourth is undernourished. Technical assistance programs of the United Nations, United States, British Commonwealth, Norway, and other groups have been aimed at reducing this hunger, but the task is not an easy one, because the dietary deficiencies are most acute in the underdeveloped countries, which are often incapable of quickly taking advantage of modern ideas and techniques. Progress is being made, however, and food production has increased wherever technical assistance has been given. Unfortunately, it has not been possible to increase the food production much more rapidly than the population increases.

A recent study of the world's food problems has been made by the California Institute of Technology, and from this research it is possible to understand the nature of the food shortage. It seems that there is no technological reason why this shortage exists. There is not enough food, because we are not utilizing the potential productivity of the land and sea from which all our food comes directly or indirectly from plants. A much greater population could be fed adequately if changes were brought about in our methods of food production.

In the field of world agriculture, the following changes are necessary. First, humans must consume directly greater proportions of plant food and decrease the amounts fed to animals; second, plants must be developed that will provide greater numbers of calories per unit area of land; third, the tremendous wastage of food through spoilage or animal depredations must be checked; and, fourth, as much land as possible must be made arable and cultivated at a maxiumum intensity. These improvements will first be made by the more developed countries and gradually adopted by the under-developed countries upon the urging of the former.

The general methods that may be applied to produce an increased supply of food from the waters are somewhat similar to those mentioned for agriculture. Knowledge of our fresh-water and marine resources is, however, not as highly developed as that of agriculture, but with increasing research we undoubtedly will better understand the complex of factors that control the nature and types of productivity in the waters. In certain types of fresh-water fish cultivation, we are already approaching the efficiency of agricultural methods.

Rather than discuss possible future trends in the yields of human food from the waters of the entire world, this committee has decided to restrict itself to North America. Observations made on the fisheries of the United States and Canada are also applicable more or less to the fisheries of other countries.

As is the case with agriculture, it would be most efficient to utilize marine plants directly as food. In North America, we are already consuming several types of marine algae, among which are the large brown kelps that yield algin, and two red algae, known as Irish moss and dulse. There are tremendous potentialities for increased production of these and other sea-weeds such as the brown rockweeds that cover much of the intertidal zones in the northern waters. These seaweeds are rich in vitamins, but unfortunately the carbohydrates that they contain, although of considerable value in industry, are not readily digestible by humans. A considerable amount of research has recently been aimed towards culturing fresh-water algae as food, but the commercial possibilities of such endeavors are as yet unknown, although they appear to be promising.

To obtain large quantities of food from the waters we must turn to the animal life which includes zooplankton, various invertebrates, and fishes. A method of economically harvesting plankton animals has not yet been devised. Many of the larger invertebrates, such as certain species of bivalve mollusks and decapod crustaceans, are being fished intensively, but there are large untapped sources of smaller, less conspicuous invertebrates that could be used for food, for example the many species of gastropods, the univalve and smaller bivalve mollusks, echinoderms, and a number of species of crabs not now eaten. Most of our increased food production, however, must be obtained from the fishes, many of which function efficiently to convert the small plants and animals into protein that is readily available to humans.

One method by which the production of fish can be increased is through the greater utilization of some of the species that are not now harvested at an optimum rate. To determine the optimum rate of exploitation of a species is a problem that only fishery biologists, in close cooperation with the fishery industry, can solve through intensive research over a considerable period of years. This is the goal of almost all biological investigations in the fisheries.

Another possibility for greater production is by means of thorough surveys of the areas not now fished commercially. Such endeavors are exploratory in nature and must be carried on until all habitats in which fish or other edible forms might dwell have been searched regularly. Deep-water regions off the coasts, mid-water areas, and seldom fished banks must be systematically investigated throughout the Northern Hemisphere. This will mean that new types of fishing gear will need to be devised, and perhaps completely revolutionary ideas will result in great changes in many of our fisheries.

Biological control of undesirable species that act as either predators or competitors with the valuable species offers another means by which the food supply may be augmented. For example, at the present time we need to control the lamprey that attacks Great Lakes fishes and the green crab that has been largely responsible for the decline in the New England soft clam population. In fresh-water, control of the fish fauna is now commonly practiced through the use of chemical killers. Ponds, lakes and streams may be stocked with edible varieties of fish after the undesirable species have been eliminated.

One of the important fish-cultural developments during the past few decades has been the use of farm ponds and reservoirs for raising fresh-water fishes. With greater knowledge of how to manage such water enclosures, and what species are most suitable, a valuable addition can be made to the countries' food supplies. Fish-farming is of tremendous importance in the Orient and parts of Europe, and we can anticipate that if necessary, we will be able to increase greatly our harvests in North American fresh waters.

The prevention of spoilage is another problem that must be investigated, if the fullest use of our marine and fresh-water resources is to be achieved. In the primary operations of the great fisheries, spoilage means more a loss of monetary value than of food value, for fish that are unsuitable for human consumption are diverted to reduction plants to be manufactured into fish solubles or meal. At the retail level, however, fish spoilage may mean a complete loss of the product, and the incidence of the rejection of decomposed fish is dependent upon the conditions which prevailed from the time the fish was caught until it reached the retailer and ultimately the consumer. Improvement in the quality of fish products is the concern of the technologists, and their increased research in the future will undoubtedly reduce the amount of fish that is entirely wasted because of spoilage.

In the future, we must consider whether available food supplies are great enough to allow us to continue the large scale feeding of livestock and poultry. Great quantities of grains, fish meal and fish solubles are fed to those animals which we in turn consume. The return of calories from the animals may be only about ten percent of the food value from the feed if it were fed directly to humans. Ultimately, we may have to eat increasing amounts of the fish meal or solubles or the fish from which these products were made. Fish meal, when specially prepared, is a palatable and valuable addition to human diets and is already being used as such in a few countries. Menhaden, herring, and sardines, the great favorites of reduction plants, could be processed in increasing quantities as human food, and trash fish now made into by-products or fed to fur animals could undoubtedy be similarly used.

If the economy of the United States and Canada continues at a level that is so much greater than most of the world, we may not have to worry about our own food supplies, but there is no doubt that our responsibilities towards other, not so fortunate, nations must force us to consider seriously the future of the world's food supplies. Before the end of the next hundred years, historians may regard this present time as one of almost incredible abundance, and the conditions that have produced food surpluses and needs for crop reductions will be considered as historical curiosities.

ted from COPEIA, 1957, No. 2, pp. 155–156, July 15
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ECORDS OF SOME GULF OF MAINE IES.—*Carcharodon carcharias* (Linnaeus); t white shark. On August 9, 1955, Ted Farrin, ator of a floating fish trap, caught a 309.9-cm. great white shark at Pemaquid Point, Lincoln nty, Maine. The specimen was sent to a Boston, sachusetts fish market to be sold as fresh shark t.

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ugil cephalus Linnaeus; Striped mullet. A 7.5- specimen was caught at Sams Cove, Muscongus , Lincoln County, Maine on September 16, . The fish had been trapped in a tide pool be- a fence designed to bar green crabs (*Carcinides nas*) from intertidal clam beds.

arda sarda (Bloch); Atlantic bonito. A 46.4-cm. imen was caught in Maurice Pye's floating fish at Small Point, Sagadahoc County, Maine on 9, 1954. According to Maine fishermen who use e traps at Pemaquid Point and Casco Bay, a en or so bonitos have been caught each summer several decades. This species is much less mon in the northern Gulf of Maine than in the thern (Bigelow and Schroeder, 1953, U. S. Fish. dl. Fish. Bull., 74: 338).

ippocampus hudsonius DeKay; Seahorse. Three female specimens have been caught while attached to Maine lobster trap buoy lines. One with a length of 9.5-cm. was found October 18, 1953, near Pumpkin Ledges, off Boothbay Harbor, Lincoln County. Another, 10.8-cm. long was taken during the same month near Kennebunk, York County. The third fish, measuring 12.8-cm., was caught October 18, 1956 at Southport, Lincoln County.

Naucrates ductor (Linnaeus); Pilotfish. During the last week of August 1949, fish trap operators at Barnstable, Massachusetts, caught a 27-cm. pilotfish in Cape Cod Bay. The local fishermen considered this an unusual fish and were not able to identify it.

Pseudopriacanthus altus (Gill); Short big-eye. On September 2, 1956, Herbert Decker of Southport, Maine, found a 2.8-cm. specimen in a lobster trap hauled up from a depth of ten fathoms. This is the first record for this fish on the Maine coast. The body color in life was orange red; the spiny dorsal fin had two rows of orange spots, two on each spine; the ventral spine had two orange spots; the iris had four white spots; and immediately above the lateral line was a row of 12 black blotches. This specimen was similar to one mentioned by Hildebrand and Schroeder (1928, Bull. U. S. Bur. Fish., 43 (1): 255), for it had two enlarged spines at the angle of the preopercle.—Leslie W. Scattergood and Gareth W. Coffin, *U. S. Fish and Wildlife Service, Boothbay Harbor, Maine.*

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ESPONSE OF LABORATORY FISH POPULATIONS TO ISHING RATES

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This experiment was designed to determine how populations of fish ary when subjected to fishing pressure, and what the yield in the orm of fish flesh would be at several fishing rates.' It was carried out t the Leetown, West Virginia, Fishery Station of the Fish and Wild- ife Service from May 1951 through July 1954. Four 10-gallon aquaria ere set up under controlled conditions of light, temperature and ood supply, and started with small populations of the guppy *Lebistes reticulatus*).

After the populations had grown to near asymptotic size (roughly 50 fish with a total weight of 30 grams) successive fishing pressures ere applied to two of them which had been selected by lot. This rovided two pairs, each of which contained one test and one control opulation. All populations were enumerated and weighed once each eek, and every third week (corresponding roughly to the guppy rood interval) removals were made from the test populations ac- ording to the fishing rate being applied.

A fuller discussion of the experiments, together with the basic data, ill be given in a report now in preparation to be submitted for pub- ication as a Fishery Bulletin of the Fish and Wildlife Service.

CHANGES DURING EXPLOITATION

The initial reaction to the imposition of a 25 per cent triweekly ex- loitation rate on populations A and B was the expected decrease in otal population numbers (Figures 1 and 2). This decrease is con- rasted with the continuing upward trends of the control populations C and D, clearly demonstrating that the decrease was the result of ex- ploitation. In both A and B the decrease was composed of an imme- iate reduction in the accumulated stock of adults followed by an initial reduction in the number of juveniles. The space and food thus made available apparently caused an improved survival rate, resulting in a new influx of juveniles and a peak of population numbers at about week 60. A further adjustment between juveniles and adults then took place, resulting in a relatively stable ratio starting with week 73.

Decreasing the exploitation rate to 10 per cent caused the numbers of both adults and juveniles to increase in A and B. The history of the two populations after week 91 differs, however. In A the increase

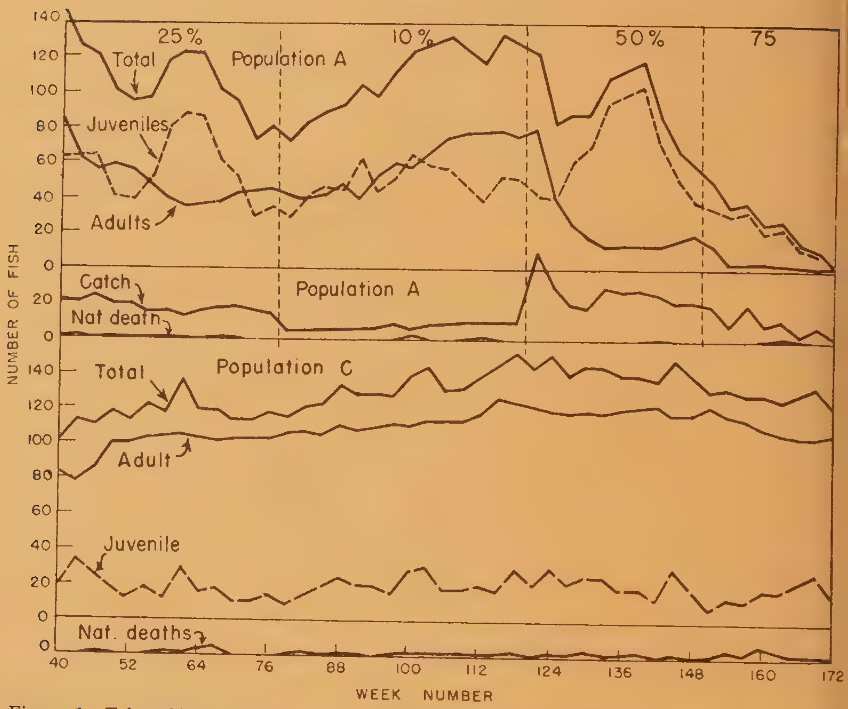

Figure 1. Tri-weekly population, catch and mortality numbers during exploitation period in populations A (test) and C (control). Percentages in upper two panels are tri-weekly exploitation rates.

in adults continued throughout the 10 per cent exploitation period while the juveniles declined (presumably as the result of competition from the greater number of adults) after week 100. In B the decline of juveniles started earlier (week 91) and was followed by a sharp increase beginning with week 109. Also, there was a decline in adult numbers after week 106. No firm hypothesis for these differences between A and B is offered, although they may result from genetic differences in reproductive rate and ability to secure food.

Changes under the 50 per cent rate resemble those occurring under the 25 per cent rate, the same initial decline in adults followed by an influx of juveniles being present. As anticipated, the final level for adults is much lower than under either the 10 per cent or 25 per cent rate.

The 75 per cent rate proved to be catastrophic for the test populations. Even though the amount of food and space per individual fish was great, this could not increase survival sufficiently to offset the loss of progeny resulting from the rapid reduction in mature adults. Both A and B proceeded steadily to extinction.

In general, the test populations demonstrated violent changes in population size and composition, coinciding with changes in exploitation rate, and not found in the control populations. It seems certain, therefore, that the changes did result from the experimental removal of fish at the stated rates.

The ''natural deaths'' (Figures 1 and 2) consist of dead fish found in the aquaria. Since most of the mortality occurs through cannibalism, these dead fish represent only a small fraction of the total mortality. However, it is of some interest that the rate of occurrence of dead fish increased during the latter part of the experiment in the two control populations, as the proportion of old fish became greater; apparently senility played some part in these deaths. In the test populations fish were cropped off so fast that there was no opportunity for an accumulation of older individuals.

The catch curves (Figures 1 and 2, center panels) verify some estab-

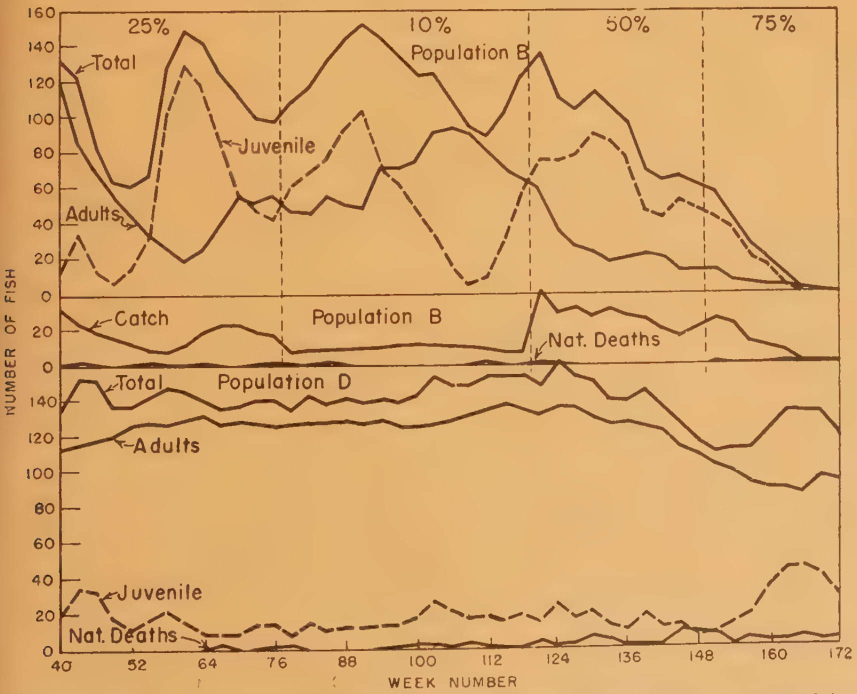

Figure 2. Tri-weekly population, catch and mortality numbers during exploitation period in populations B (test) and D (control). Percentages in upper two panels are tri-weekly exploitation rates.

lished principles of fishery exploitation: (a) at such low levels of exploitation as 10 per cent the catch is stable but below what the stock is capable of producing, (b) increase of the rate from 10 per cent to 50 per cent produces a large temporary increase in catch, followed by a decrease and stabilization at a level lower than the initial, but higher than that at the 10 per cent rate, (c) at the 75 per cent rate both catch and stock decline steadily—this is true "overfishing."

EQUILIBRIUM YIELDS

A rigorous definition of equilibrium in an exploited population would require that all vital rates—recruitment, growth, fishing mortality, natural mortality—be constant. In such a population the age, size and sex composition would be absolutely unvarying, and the yield would, of course, be constant. It is extremely unlikely that such a condition would ever obtain in any natural population, even if the fishing rates were held constant, for fluctuations would be imposed by changes in such aspects of the environment as food supply and temperature. Even under laboratory conditions it is hardly possible to control every source of variation. Thus only by observations over a very long period of time could average values for the "equilibrium" constants be obtained.

In the present experiment it has been necessary to forego such long-term observations. Even as performed the work required over three years to observe the effects of four exploitation rates. It was felt that a close approximation to equilibrium conditions would obtain when a given exploitation rate had been maintained long enough so that there were no longer significant unidirectional changes in population composition. Observation of such a condition for a period of six weeks was the criterion for changing to another exploitation rate. It is felt that yields obtained during these periods represent good approximations of the average yields which would be obtained under long-term equilibrium conditions.

Comparison of the yields of the two test populations showed that they were almost identical at each exploitation rate. Application of the t test indicated no significant difference (P approximately 0.2) and averaging of the yield data was therefore justified. The resulting mean yields gave a more consistent representation of the relation between exploitation rate and yield than did the data for the individual populations.

The empirical relation between rate of exploitation and yield (Figure 3) is reminiscent of a parabola, but considerable experimentation did not reveal it to conform to any simple mathematical formula. A difficulty arose in locating the second intersection with the x-axis.

Since the populations were extinguished at the 75 per cent rate, it was known that yield there was zero. It is possible, however, that the point of zero yield might be reached anywhere between the 50 and 75 per cent rate. Thus the intersection has been bracketed but not located (and is so indicated in Figure 3).

The equilibrium yield curve has verified the contention of Sette (1943) that "A population has its maximum increase when it is neither at its maximum nor minimum size but when middling in size; and that is the level at which the most individuals can be regularly removed and still be fully replenished by the population's inherent tendency to grow." The empirical curve indicates that the maximum equilibrium yield for the guppy populations would occur at tri-weekly exploitation rates between 30 and 40 per cent; the population mass at these rates would be between 10 and 15 grams.

It is of interest to calculate the rate of food conversion at the maximum equilibrium yield. The maximum of the empirical yield curve depends somewhat on the subjective fitting by inspection, but the maximum *observed* yield was 3.5 grams per three-week period. The amount of food consumed per such period was 17.1 grams. The indicated efficiency of food conversion is thus 20 per cent. Modern hatchery practice yields "conversion ratios" (pounds of food per pound of fish produced) of 2.35 to 4.95 for salmon (Burrows *et al.*, 1952), equivalent to efficiencies of 42 and 20 per cent, respectively. Data of Markus (1932) indicate an efficiency of 23 per cent for large-mouth bass. The results for the guppy populations are thus close to those recorded for other species.

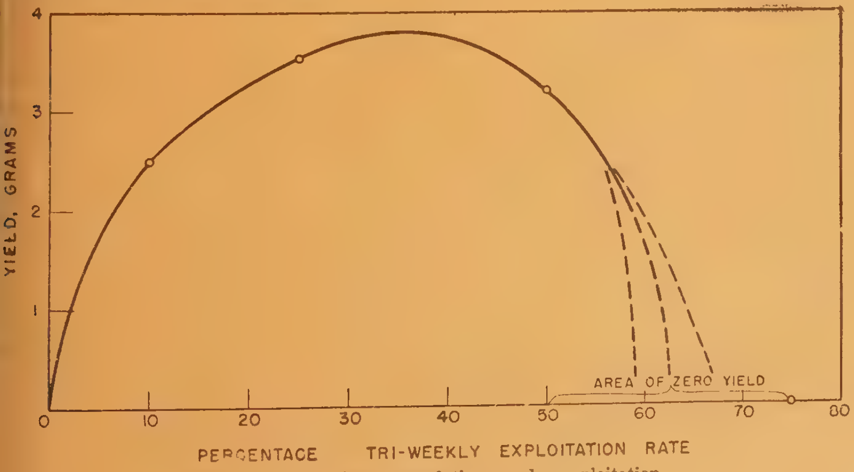

Figure 3. Yield of test populations under exploitation.

Comparison of the efficiencies of food conversion at the three non-lethal exploitation rates indicates that the 25 per cent exploitation rate is most efficient, converting 20 per cent of the food consumed into fish flesh. Efficiencies for the 10 and 50 per cent exploitation rates were 15 and 19 per cent, respectively.

INFORMATION FROM CONVENTIONAL MEASURES

A pertinent question is: What could the intelligent fishery administrator have learned about the populations under exploitation, from a study of conventional fishery data? In an attempt to answer this, the three series: catch, catch-per-unit-effort and average length of individual fish in the catch, were brought together for examination. Data from the two exploited populations were combined in order to eliminate some of the variability not related to exploitation rates, inasmuch as previous comparisons had revealed the series for populations A and B to be similar in their essential features.

The start of a virgin fishery at the 25 per cent exploitation rate was followed by the inevitable decline in both catch and catch-per-unit, reflecting a real decline in population size. After week 58, however, relative stability prevailed, and indicated that the stocks could stand the drain of the fishery being imposed upon them. The decrease in catch at the 10 per cent rate might have been ''viewed with alarm'' were not the catch-per-unit and average length measures available. These, however, showed that the population was actually increasing in mass and in average size of individual fish. Data from the previous history of the fishery (25 per cent rate) would indicate that the 10 per cent exploitation rate did not utilize the full productivity of the stocks.

The sharp decline in catch, catch-per-unit and average length after imposition of the 50 per cent rate most resembles the situations that have caused alarm among those concerned with real fisheries. Inspection of the equilibrium yield curve (Figure 3) indicates that the 50 per cent rate was indeed somewhat past the point of maximum return. If the history of the catch under the 25 per cent rate were available, it would have become obvious at about week 142 that nothing was being gained by the additional fishing effort being put forth, and the fishery could have been cut back to an intermediate level in an attempt to secure a better yield at less cost. If the fishery had been started at the 50 per cent level, the data would be difficult to interpret, but such a situation is unlikely among actual fisheries, which practically always start small and gradually increase. The value of securing as complete biological data as possible from the inception of a new fishery is sharply pointed up.

Finally, it is of interest to know if the doom of the stocks at the 75 per cent rate could have been foreseen. Certainly, if the previous history of the three measures were available, it would have become quickly apparent that the additional effort was not only depressing population size and average fish length, but was actually decreasing the catch Under such circumstances, even the most optimistic fishing industry would probably be convinced of the need to retrench.

PRINCIPLES OF EXPLOITATION

Fishery biologists may think we presume a great deal when we venture to generalize for full-scale commercial fisheries from observations on our laboratory populations of guppies. True, the differences between the vast diffuse marine populations which form the object of most of our large fisheries, and the self-contained populations of guppies in their tiny laboratory tanks are immense. They seem no greater, however, than the differences between laboratory populations of mice or guinea pigs and populations of human beings; yet the results of experimentation on the former have often been successfully applied to the latter, particularly in fields such as pathology where experiments with human beings could not be carried out.

One principle of exploitation, already established theoretically, has been verified by the present experiments: that even a low rate of exploitation causes some change in population size. Thus the equilibrium mass of the populations exploited at the 10 per cent rate was about one-third less than the asymptotic mass of the unexploited control populations. It is demonstrated that a finding of simple reduction in population size is not *in itself* a cause for alarm or retrenchment.

A second principle of exploitation is that fish populations up to a certain level of exploitation are resilient, responding to removals with increased survival and growth rates. The effect of resiliency in restoring a population to a higher level of abundance after reduction in exploitation rates, is brought out by the increase in mass of both exploited populations to an equilibrium level about 50 per cent greater than that prevailing under the 25 per cent exploitation rate, after reduction of the rate to 10 per cent.

A principle complementary to that of resiliency is that if a population of the type considered here is reduced below a critical level, it will not recover, but continue to decline until extinction. Only about 20 reproductive periods were required to extinguish the guppy populations at the 75 per cent exploitation rate, although it is true they had already been considerably reduced by application of the 50 per cent rate.

Perhaps the most important principle of exploitation is that there exists for each population, somewhere between zero and lethal exploitation rates, a rate of exploitation at which the maximum equilibrium yield will be produced. This is not a new idea, of course, but the laboratory experiments have provided verification and demonstration of it. Results reported above indicate that for laboratory populations under the controlled conditions imposed, and with a constant supply of food, the maximum return is obtained under exploitation rates of 30 to 40 per cent per reproductive period, when population mass is at about one-third its asymptotic level.

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DISCUSSION

DR. MCHUGH: I am sure you will agree that this is a very interesting and a very significant paper. It is the first time, to my knowledge, that the question of the population dynamics of a fishery has been demonstrated experimentally. It has been done with other organisms but never before, to my knowledge, with fishes; and I think it must give people like Mr. Schaefer and others, who have been working on a combination of the theoretical side of this problem in connection with the observations they have been able to get from existing fisheries (which are admittedly subject to wide errors) a good deal of confidence that, in the methods they are using, they are certainly on the right track.

DR. CRONIN: I would like to ask Mr. Silliman one question about his excellent paper.

Whenever you had significant exploitation it seemed to be followed by high survival or a significant increase in juveniles, is that consistent?

MR. SILLIMAN: Yes; that usually occurred, except at the very highest rates of exploitation when everything decreased.

DR. CRONIN: I wonder what the mechanism of that increased crop of juveniles was. Was it decreased cannibalism or increased fecundity; or to what do you ascribe it?

MR. SILLIMAN: It is difficult to tell, since all we had were some fish in a tank; but I think it was probably due to two things: One was a decrease in cannibalism which, after all, is a form of competition for food; and the other was the actual decrease in competition for food, since the total amount of food was held constant.

DR. CRONIN: Do you know whether the size of broods changed in response to the fishing rates?

MR. SILLIMAN: No; I had no way of knowing what the size of the brood was. They were simply born in the tanks; and I could not tell.

MR. WURTZ: Just as a matter of idle curiosity, Dr. Silliman, I would like to know what the absolute size of your populations was, and the containers in which you ran your experiments.

MR. SILLIMAN: It was about 150 fish. The asymptotic level was about 150 fish in ten-gallon aquaria.

DISEASES OF FISHES OF THE WESTERN NORTH ATLANTIC

V. PARASITES AS INDICATORS OF HERRING MOVEMENTS

By

Carl J. Sindermann

U. S. Fish and Wildlife Service

RESEARCH BULLETIN No. 27

(This paper is one of several reports resulting from the herring investigation carried on jointly by the U. S. Fish and Wildlife Service, the Maine Department of Sea and Shore Fisheries, and the Maine Sardine Industry)

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ABSTRACT

To determine whether the distribution and abundance of parasites might furnish information about populations and movements of sea herring, a study has been made of the incidence of fungus (*Ichthyosporidium hoferi*), myxosporidian (*Kudoa clupeidae*), larval cestodes (Trypanorhyncha), larval nematodes (Anisakinae), and trematode (*Brachyphallus crenatus*) in mature herring of the western North Atlantic, as well as in herring of age groups 0 and 1 from the Gulf of Maine. Results of this study indicate definite geographic variation in distribution of certain parasites, and suggest a lack of intermixing of adult herring of the Gulf of Maine with those of the Gulf of Saint Lawrence; and a possible separation of populations of immature herring from eastern and western parts of the Gulf of Maine, with no major lateral movement along the Maine coast between the first and second years of life.

I. INTRODUCTION

Parasites and diseases of sea herring have been noted in previous years (Linton 1901, Manter 1925, Heller 1949) and have been studied specifically at the Boothbay Harbor, Maine, laboratory of the U. S. Fish and Wildlife Service during the past several years. Research has been concentrated on a systemic fungus disease (Scattergood 1948, Sindermann and Scattergood 1954, Sindermann 1956), but other parasites of this fish have also been examined in some detail (Sindermann and Rosenfield 1954a, 1954b). Parasites of herring of the western North Atlantic include: a monogenetic trematode (*Gyrodactylus* sp.) from the gills, copepods (*Caligus rapax* and *Argulus alosae*) from the body surface, a larval trematode (*Cryptocotyle lingua*) from the skin and musculature, larval nematodes (Anisakinae) from the mesentries, a systemic fungus. (*Ichthyosporidium hoferi*), an adult trematode (*Brachyphallus crenatus*) from the stomach, a myxosporidian (*Kudoa clupeidae*) from the body muscles, larval cestodes of the order Trypanorhyncha from the mesenteries, and a gram negative bacillus which causes "tail rot". Some of these, such as the larval nematodes (Anisakinae) and the trematode *Brachyphallus crenatus* are no doubt benign, and probably exert little if any impact on the population, while others, such as the fungus and the bacterium, are pathogenic.

While it is important to assess the effects of parasites and diseases of the herring, it may also be that a study of the nature and degree of parasitization might furnish indications of the movements of herring and information concerning the existence and extent of intermixing of populations of herring along the North American east coast. It was with these latter possibilities in mind that the study here reported was undertaken.*

The complicating and limiting factors in an investigation with such an orientation are many:

(1) Kinds and numbers of parasites may vary seasonally, geographically, and with age of the host. Parasite abundance may be affected by differential mortality, which may vary seasonally or with age of the host.

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*The author wishes to express his appreciation for the assistance of Alden Stickney, Louis Taxiarchis and other members of the staff of the Fisheries Laboratory at Boothbay Harbor.

(2) There may be a differential distribution of intermediate or alternate hosts—so that the parasite picture may reflect variations in distribution or abundance of organisms other than herring.

(3) Physical factors such as temperature may influence the abundance or nature of parasites found.

(4) There may be long-term fluctuations in abundance of particular parasites which would not be revealed by a short-term study.

Despite these limitations, studies of the nature and degree of parasitization, when combined with other criteria for population analysis and with other methods of studying herring movements, may furnish insights into these problems.

Intensive sampling was made in 1955 and 1956 of herring of three sizes: (1) herring of age group 0 (known as "brit") from the Gulf of Maine, sampled in the autumn of 1955; (2) herring of age group 1 (known as "sardines") from the Gulf of Maine, collected in early summer of 1956; and (3) mature herring from the Atlantic coast of United States and Canada, sampled throughout 1955 and 1956. In addition, sardine herring from the Bay of Fundy were examined from September 1955 to September 1956 for seasonal influences on parasitization. This is the only area known to the author where herring are taken year-round. Wherever possible, samples consisted of 100 fish, irrespective of the size of the lot from which they were taken.

Parasites included in this study were: fungus (*Ichthyosporidium hoferi*), myxosporidian (*Kudoa clupeidae*), trematode (*Brachyphallus crenatus*), larval nematodes (Anisakinae), and larval cestodes (Trypanorhyncha). The fungus parasite has already received extensive attention elsewhere (Cox 1916, Daniel 1933a, 1933b, Fish 1934, Forster 1941, Scattergood 1948, Sindermann and Scattergood 1954). It seems to be acquired in inshore areas, affects all age groups of herring, and is of terminal nature in many fish. Epidemic outbreaks of this disease in herring are a matter of record in 1913-1914 and 1954-1956 in the Gulf of Saint Lawrence (Cox 1916; Leim 1955, 1956; Sindermann 1956) and in 1931 and 1947 in the Gulf of Maine (Fish 1934; Daniel 1933a, 1933b; Scattergood 1948).

Myxosporidian infection of immature herring has been noted by Linton (1901), Hahn (1918), and Sindermann and Rosenfield (1954a). Infection occurs very early in the life of the herring, since gross, fusiform intramuscular cysts containing thousands of myxospores have been found in fish only nine months old. Spore release from such cysts seems to occur during the second and third years of life of infected fish, often resulting in ulceration of the skin overlying the area. Presence of cysts or typical ulceration was used as a criterion of infection during the present survey. The same myxosporidian species has been found in immature alewives during this survey, and has been reported from young alewives, blueback, and menhaden (Tyzzer 1900, Linton 1901, Hahn 1918, Meglitsch 1947), in addition to young herring.

The trematode *Brachyphallus crenatus* has been reported previously from the herring (Cooper 1915, Manter 1925, Linton 1940, and Heller 1949). This worm is usually found in small numbers in the stomachs of herring of all age groups, although it has been recorded in hundreds during the present study from individual mature herring feeding on chaetognaths. Many of the worms found in those fish were immature and probably recently liberated. Myers (1956) has reported the presence of a closely related worm in the chaetognath *Sagitta elegans*.

Larval cestodes of the order Trypanorhyncha, including *Grillotia erinaceus* and *Lacistorhynchus tenuis*, have been reported previously from herring by Linton (1901) and Dollfus (1942). They occur in club-shaped or oval glistening white cysts in the mesenteries, particularly in the region of the pyloric caeca, and also in the stomach wall. The definitive hosts for these worms include elasmobranch fishes such as dogfish and skates, while crustaceans serve as the first intermediate hosts (Young 1955, Ruszkowski 1932).

Larval nematodes, Anisakinae, are common in herring of all ages, usually occurring in small numbers in any individual fish. They are found free and migratory in the viscera of young herring, and coiled and encysted in the mesenteries of mature fish, especially adjacent to the pyloric caeca and posterior to the stomach. Such larval nematodes have been reported previously from herring of the Gulf of Saint Lawrence (Heller 1949), and their definitive hosts include marine mammals.

II. PARASITES OF BRIT (AGE GROUP 0 HERRING) FROM THE GULF OF MAINE

Herring spawn in late summer and autumn in the Gulf of Maine, and the progeny first appear inshore as larvae in early winter and in estuaries and coves as brit the following spring. These small herring enter the fishery in late summer and early autumn when they reach a size acceptable to sardine processors (some may be taken earlier than this in Canadian waters for use in extracting pearl essence and for reduction). To reduce possible seasonal influence on extent of parasitization, samples were taken from sardine catches along the entire Maine coast during the three-month period September 1 to November 30, 1955. During this period, samples from any one point exhibited no observable consistent change. Figure 1 indicates locations of sampling and percentages of myxosporidian, nematode, and trematode parasitization.

Examination of the data obtained indicates the following:

(1) No cestode larvae were found in any of the group 0 herring examined.

(2) Fungus infection was found in only one fish in one sample (West Quoddy Head). This disease has been at a very low ebb in the Gulf of Maine for several years, although it was very abundant in the Gulf of Saint Lawrence in 1955, and was abundant in immature herring of the Gulf of Maine in 1947.

(3) Myxosporidian infections displayed a most interesting distribution, with extremely high incidence in Casco Bay and (with the exception of a short transition zone) no infections whatever along the eastern Maine coast. A full report on myxosporidiosis in young sea herring is in preparation.

(4) Larval nematodes were more abundant in samples from the eastern Maine coast than from west of Penobscot Bay. Unlike the coiled encysted worms from mature herring, larval nematodes from brit herring were small, free, and apparently migratory.

(5) Trematodes displayed highest incidence in Penobscot Bay and lowest incidence at the mouth of the Bay of Fundy.

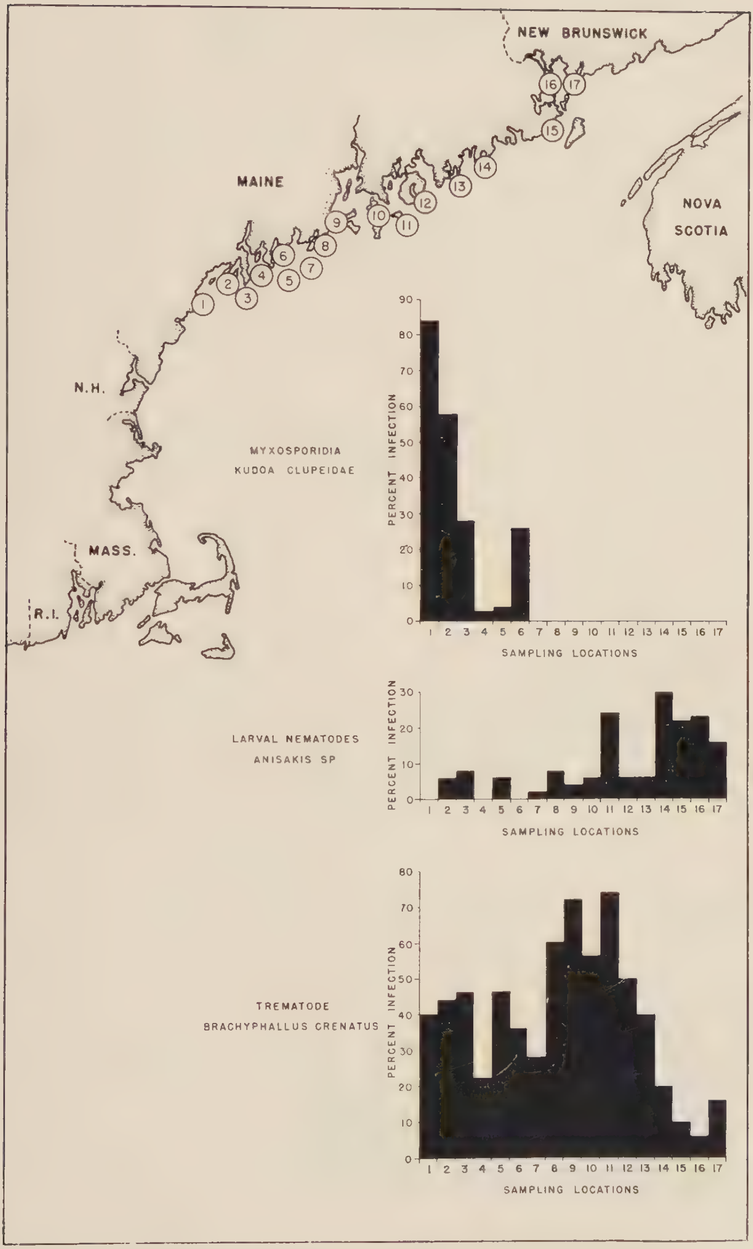

Figure 1. Incidence of certain parasites in age group 0 herring (brit) from the Gulf of Maine in the autumn of 1955. Numbers, indicating sampling locations, encircled on the map, correspond to numbers on the graphs.

III. PARASITES OF SARDINE HERRING (AGE GROUP 1) FROM THE GULF OF MAINE

The youngest age group of herring, referred to in Part II, disappears to a large extent from the coves and estuaries of the Maine coast in late autumn, to reappear as age group 1 the following spring and summer, when it is fished extensively for use as sardines. Little information is available concerning the movements of these herring along the Maine coast between the first and second years of life, and it was felt that re-examination of the nature and distribution of parasitization of these immature fish during their second year of life might provide some indications of movement, when compared with figures for brit. This seemed especially promising in view of the remarkably discontinuous incidence of myxosporidian infections in brit. As far as possible, sampling of sardine herring paralleled the previous sampling for brit. Locations of sampling and incidence of myxosporidia, nematodes and trematodes are indicated in figure 2.

Results of this examination are as follows:

(1) Cestode larvae were found in four samples of group 1 fish from the northern Massachusetts and western Maine coast and were completely absent from eastern Maine, New Brunswick and Nova Scotia samples. Incidence in the four samples was: Ipswich 8%, Bailey Island 4%, Cliff Island 2%, and Vinalhaven 2%. (Samples of this year class taken in December 1956 and January 1957 from Block Island Sound disclosed incidence up to 74%, with up to 17 worms in individual fish.)

(2) Fungus infection was found in only one fish in one sample (Kennebunkport).

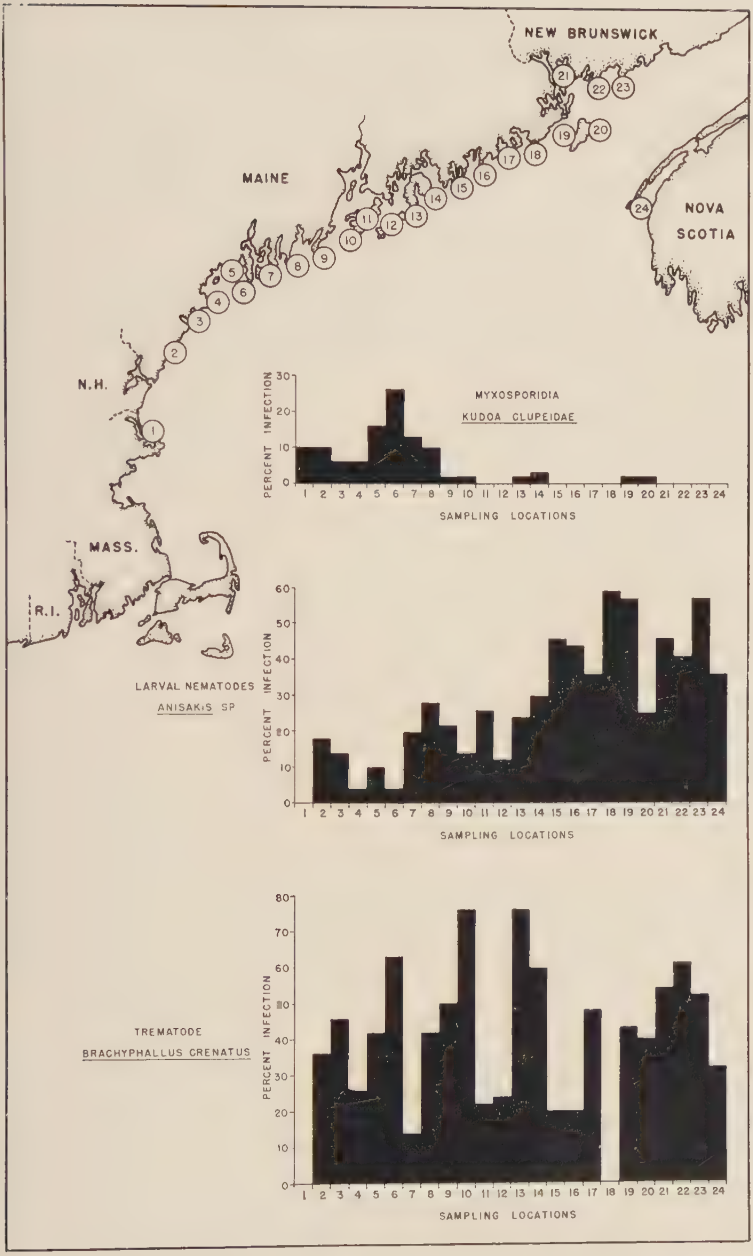

Figure 2. Incidence of certain parasites in age group 1 herring from the Gulf of Maine in summer of 1956. Numbers, indicating sampling locations, encircled on the map, correspond to numbers on the graph.

(3) Myxosporidian infections paralleled the previous autumn's figures to a large extent, but with notable exceptions. Infections in Casco Bay were reduced to an average incidence of 34% from the previous autumn incidence of 56%, and infections were found in fish from Penobscot Bay and as far east as Mount Desert Island, and also at Grand Manan Island and Channel, while the previous autumn's sampling disclosed no infections further east than South Bristol.

(4) Nematode incidence was again higher to the east of Mount Desert Island than in the area to the west. Some of the larval nematodes were coiled and encysted, some were small and migratory, and some were dead.

(5) Trematode incidence again varied locally, with some indication of a peak in Penobscot Bay as in the brit sampling of the previous autumn.

V. PARASITES OF MATURE SEA HERRING FROM THE EAST COAST OF NORTH AMERICA

Sea herring of the western North Atlantic mature at three or more
ars of age and spawn either in spring or autumn, depending on
ality. They are fished intensively during and after spawning runs.
mpling of mature fish for parasite examination, done throughout
55 and 1956, concentrated on fish taken during such times, although
ne samples were obtained during other months of the year. The
a of sampling extended from Newfoundland to Rhode Island. In-
lence of fungus, larval cestodes, and larval nematodes and the loca-
ns of sampling in 1955 and 1956 are indicated in figures 3, 4 and 5.

These data demonstrate that:

(1) Larval cestodes were absent from the Gulf of Saint Lawrence samples. This agrees with previous work in Chaleur Bay (Heller 1949) in which this parasite was not reported. Incidence was low along the Nova Scotian coast, and in the eastern Gulf of Maine, but was remarkably higher in the few samples from Gloucester, Georges Bank, and below Cape Cod.

(2) Fungus infections were extremely abundant in the Gulf of Saint Lawrence in 1955 and 1956, especially in Chaleur Bay. The western Gulf experienced widespread mortalities of herring due to this fungus disease, and a more extensive treatment of this outbreak has been reported elsewhere (Sindermann 1956). Incidence along the coast of Nova Scotia was moderate to light, while incidence in the Gulf of Maine was very light.

(3) No myxosporidian infections were found in any mature herring sampled. This disease appears to be confined to immature herring, with principal intramuscular infection during the first year of life and principal spore release during the second and third years of life of the fish host.

(4) Larval nematodes were present in varying percentages in all samples of mature herring examined, without forming any recognizable pattern. The only conspicuous change from 1955 to 1956 was the increased incidence in the Newfoundland sample.

(5) Trematodes did not disclose any consistent pattern in adult herring, probably since they are transient occupants of the digestive tract. Incidence may be highly modified by season and diet.

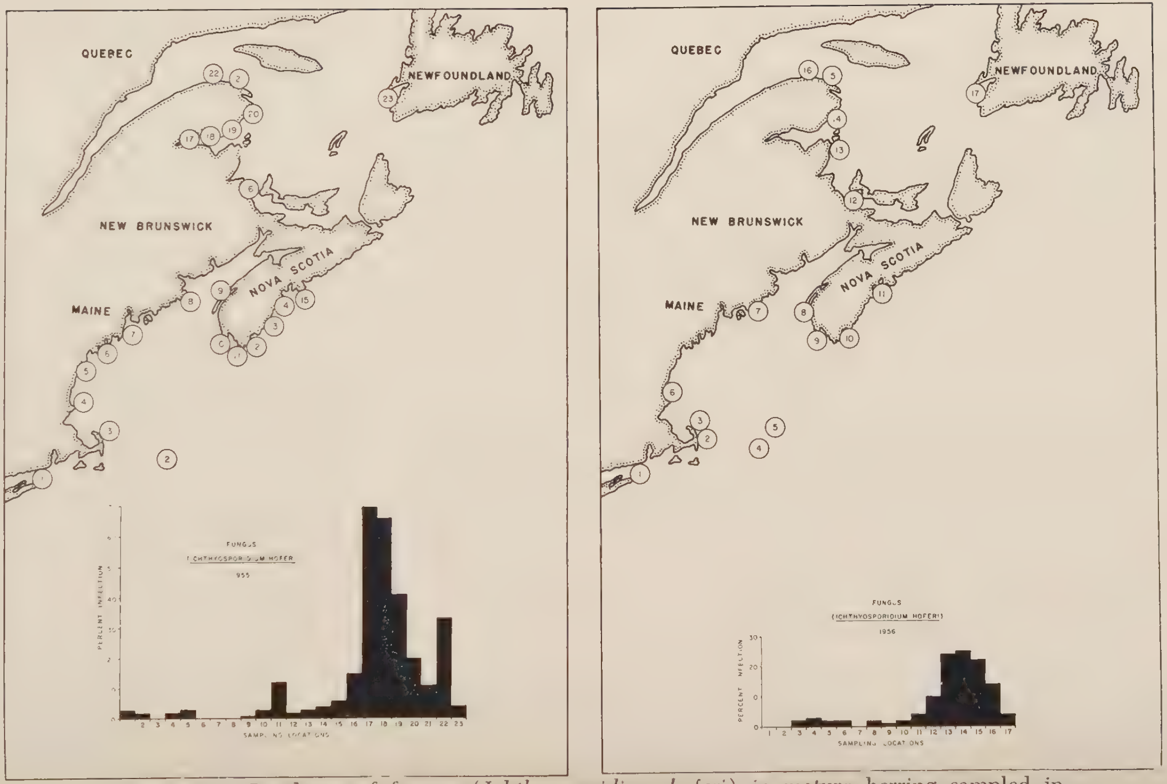

Figure 3. Incidence of fungus (*Ichthyosporidium hoferi*) in mature herring sampled in 1955 and 1956. Numbers, indicating sampling locations, encircled on the maps, correspond to numbers on the graphs.

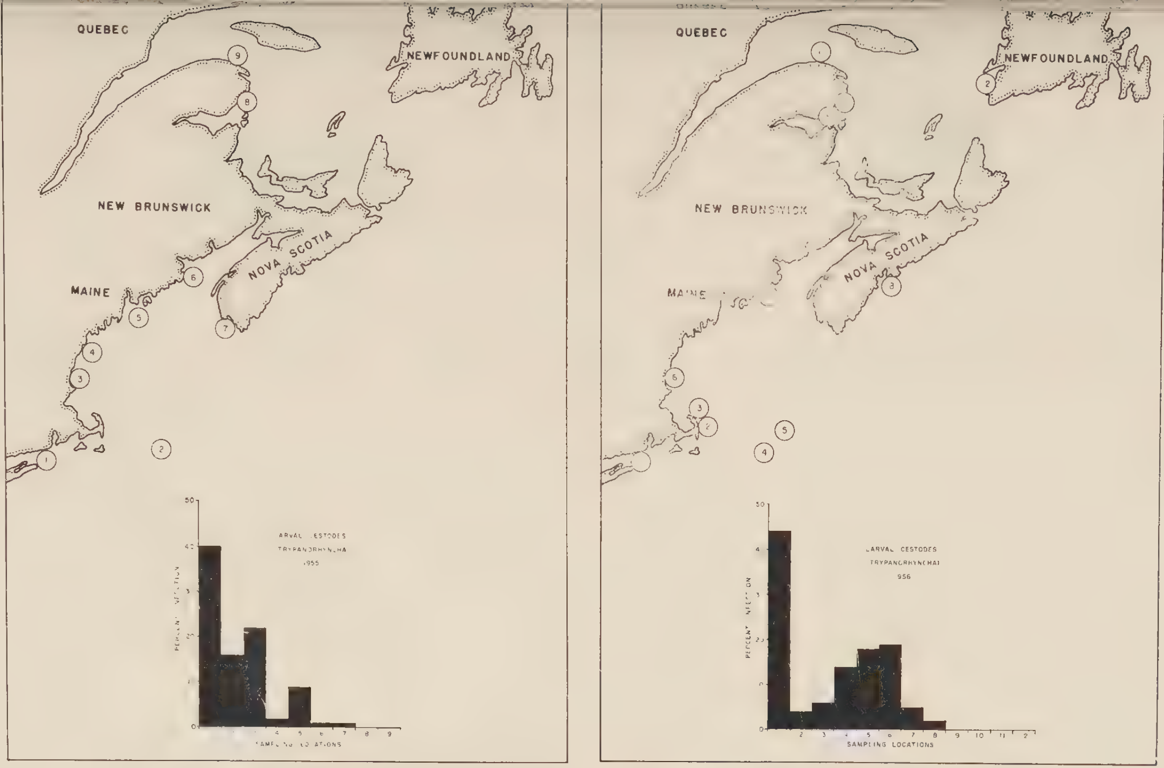

Figure 4. Incidence of larval cestodes (Trypanorhyncha) in mature herring in 1955 and 1956. Numbers, indicating sampling locations, encircled on the maps, correspond to numbers on the graphs.

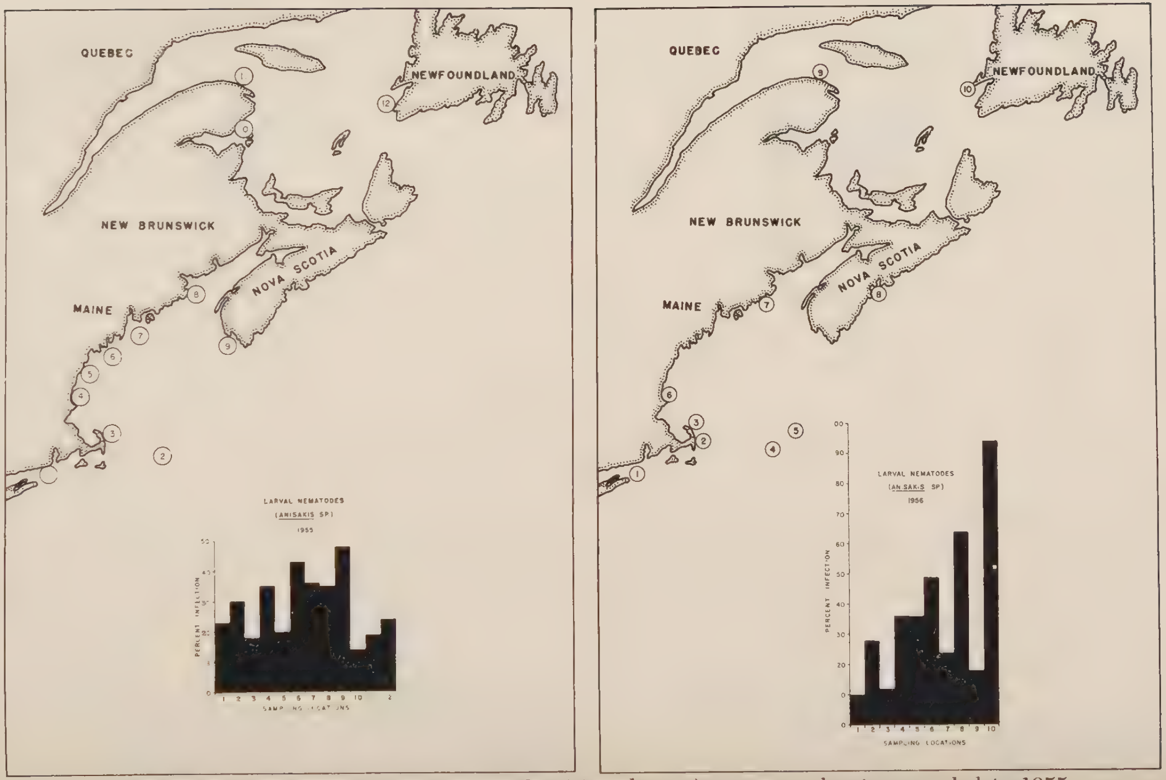

Figure 5. Incidence of larval nematodes (*Anisakis* sp.) in mature herring sampled in 1955 and 1956. Numbers, indicating sampling locations, encircled on the maps, correspond to numbers on the graphs.

V. SEASONAL VARIATION IN PARASITIZATION OF IMMATURE SEA HERRING FROM THE BAY OF FUNDY

Because of the likelihood that certain of the parasites considered in is paper may vary in abundance on a seasonal as well as geographic sis, a year-round study was made of immature herring from one ea—the Bay of Fundy—where a fishery exists on a year-round basis. mpling was begun in September when the fish were one year old, d continued throughout the second year of life of this age group. cation of the sampling and incidence of larval nematodes and trematodes from autumn 1955 to autumn 1956 are indicated in figure 6. amination of these data indicates that:

(1) Incidence of larval nematodes rose sharply in early winter, then stabilized at a somewhat lower level during spring and summer.

(2) Incidence of trematodes was quite definitely influenced seasonally, with a minimum in winter and a marked rise in spring. This trematode seems to be a transient occupant of the stomach of the herring, and the incidence changes probably reflect the nutritional state of the host. This agrees with observations made by Hansen (1955) on incidence of the closely related trematode *Hemiurus luheii* in herring of the North Sea.

(3) No myxosporidian or larval cestode infections were found in this age group from this area.

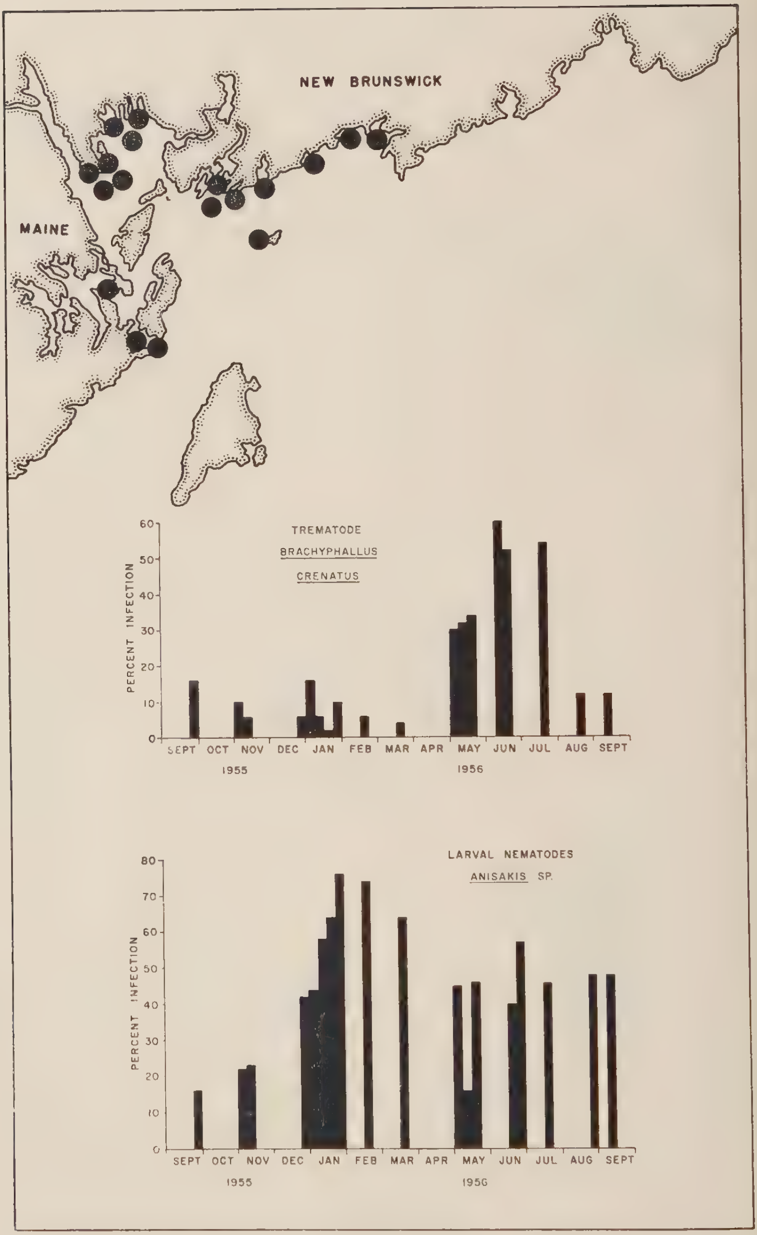

Figure 6. Locations of sampling and seasonal incidence of trematodes and larval nematodes in immature herring of the Quoddy region 1955-1956.

VI. DISCUSSION

Parasites of fishes, especially of those fish species which may participate in extensive migrations, should prove useful as tools for detecting movements of the hosts, and in elucidating populations and intermixing of populations of the host species, without implying genetic significance. Very extensive sampling over extended periods, and careful systematic study of parasites are requisites. Some beginnings in this direction have been made with certain parasites of the cod (Sproston and Hartley 1941), redfish (Herrington 1939, Perlmutter 1953, Templeman 1953), Pacific salmon (INPFC 1956, Margolis 1956), and Pacific herring (Bishop and Margolis 1955). The two-year study of certain parasites of the sea herring of the western North Atlantic reported in this paper has provided information that may prove to be of value in determining the nature of movement and of possible population boundaries for this species. Although the number of samples in some cases was limited, it was felt that the data obtained were of sufficient value to be reported here, in view of the present importance of understanding the nature of the stocks and movements of herring. The following interpretation of results should be recognized as tentative, and may require revision as more intensive study is made.

(1) Incidence of fungus disease in mature herring is definitely not homogeneous, and indicates little intermixing of Gulf of Saint Lawrence and Gulf of Maine adult herring. These areas seem to be in exactly opposite phases of an epidemic wave—with an epidemic peak and high disease incidence in the Gulf of Saint Lawrence and a low endemic level with few infections in the Gulf of Maine in 1955 and 1956. Incidence figures may be influenced by death of infected fish and by season of sampling, but this should not materially alter the pattern seen. The distribution of fungus disease in 1955 and 1956 was quite different from that in 1947, when it was abundant in the Gulf of Maine and negligible in samples from the Gulf of Saint Lawrence. Fungus outbreaks have been reported in herring of the western North Atlantic in 1913-14, 1931, 1947, and 1954-56, but not from the two gulfs simultaneously—either one or the other area was involved in each outbreak. These facts suggest a possible oscillation in disease abundance between the two gulfs and a separation of the herring stocks of the two areas.

(2) Larval cestode incidence in mature fish also supports this concept of lack of effective intermixing of adult herring from the two gulfs, since this parasite is first obvious in age group 1 fish from the southern Gulf of Maine, but is absent even from mature fish in the Gulf of Saint Lawrence samples. High cestode incidence in mature herring of the southern Gulf of Maine and below Cape Cod suggests some possible discontinuity here, with a fairly high degree of intermixing in the southern Gulf of Maine. This is further suggested by the fact that incidence of larval cestodes in age group 1 herring in 1956 closely paralleled the geographic distribution found in mature fish, with high incidence below Cape Cod, rapidly decreasing incidence in the southern Gulf of Maine and absence of the parasite in this age group from the northern Gulf. The general picture here is one of decreasing larval cestode incidence with increasing latitude. This might be related to the distribution and abundance of the first intermediate hosts or the definitive hosts, but even so, extensive migrations on the part of mature herring should result in a more homogeneous distribution of the worm in such herring than has been found to be the case.

(3) Myxosporidian parasitization of immature herring, since it is uncomplicated by intermediate hosts, seems most likely to contribute to understanding of movements and degree of intermingling of herring from different coastal areas. Aquarium experiments, feeding myxospores to age group 0 and 1 herring, have not produced infections in several trials, suggesting that the parasites may be acquired very early in the life history of individual fish. This is further suggested by the fact that myxosporidian cysts have not been found in mature herring examined during this survey, and incidence in age group 2 fish is less than in age group 1, which in turn is less than in age group 0. Results of aquarium survival experiments indicate a lack of differential mortality in infected and uninfected group 0 herring, and this is supported by the fact that the relative proportions of "light", "moderate" and "heavy" infections remain constant when comparing group 0 and group 1 herring.

The myxosporidian cyst, in view of this evidence, should serve as a reliable "natural tag" during the first few years of existence of individual herring. The fact that in this study such "marked" herring during their second year of life displayed a distribution quite similar to that in evidence during the latter part of their first year of life suggests that lateral movement along the Maine coast during the intervening time was not great. The pattern of myxosporidian infections indicates a possible separation of immature herring from the eastern and western parts of the Maine coast, at least during this phase of their lives, with an approximate transition zone in the area from Cape Small to Mount Desert Island. Incidence of this protozoan parasite suggests that lateral movement of age group 1 fish from west to east along the coast is slight, but movement from east to west may be greater, so that lower incidence in group 1 herring from the western coast may be due to dilution of infected fish by uninfected fish from the east.

(4) Larval nematodes are more abundant in both age group 0 and age group 1 herring from the eastern Maine coast than from the western coast. As with the myxosporidian infections, except in an inverse way in terms of incidence, there seems to be an approximate transition zone in the vicinity of Penobscot Bay. While the pattern disclosed might possibly reflect the distribution of other hosts in the life cycle of the parasite, the persistence of a difference in frequency of occurrence in fish of one year class sampled during the first two years of its existence suggests, when combined with myxosporidian infections, no major movement of immature herring along the Maine coast, and some separation of herring of eastern and western parts of the Gulf of Maine, at least during the first two years of their lives.

In summary, parasite distribution and abundance disclosed by the present study suggests (a) that there is little if any interchange between herring populations of the Gulf of Maine and the Gulf of Saint Lawrence, and (b) that there may be at least two subpopulations of juvenile herring in the Gulf of Maine—eastern and western—intermixing less than 25%, with a zone of intermixing between Cape Small and Mount Desert Island. These of course are tentative conclusions, contingent on findings through more established methods of analysis such as vertebral counting, age and growth studies, and tagging experiments.

VII. CONCLUSIONS

1. Fungus disease of adult herring was abundant in the Gulf of Saint Lawrence in 1955. Incidence of disease in some samples reached 70% in that year. At the same time, the disease was at a low endemic level in the Gulf of Maine, with infections from 0-3% in samples obtained.

2. Occurrence of larval cestodes in mature herring decreased with increasing latitude, being most abundant south of Cape Cod and in the southern Gulf of Maine, but entirely absent from Gulf of Saint Lawrence samples.

3. Incidence of larval nematodes in juvenile herring of the Gulf of Maine was greater in eastern samples than in western, in both age group 0 and 1 fish. A year-round examination of incidence of this parasite in the Bay of Fundy indicated a peak in early winter.

4. Myxosporidiosis was a common disease of juvenile herring from western areas of the Gulf of Maine, particularly Casco Bay, in 1955 and 1956. Evidence to date suggests that the disease organism invades the fish in the early months of life, but that it does not cause differential mortality between the first and second years of life of the herring. Examination of the 1954 year class when its members were 12 months old and again when they were 21 months old disclosed no major shift in incidence laterally along the coast of the Gulf of Maine.

5. Lack of homogeneity in incidence of fungus and larval cestode parasitization of mature herring, and of larval cestode, larval nematode, and myxosporidian parasitization of juvenile herring, cannot be explained wholly on the basis of differential distribution of intermediate hosts or definitive hosts, but may reflect lack of extensive movement and intermixing of herring of the western North Atlantic.

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Appendix 1. PARASITES OF BRIT (Age Group 0)

Location of Sampling	Date	Percent Incidence of Myxosporidia *Kudoa clupeidae*	Percent Incidence of Larval Nematodes (*Anisakis* sp.)	Percent Incidence of Larval Cestodes (Trypanorhyncha)	Percent Incidence of Trematodes *Brachyphallus crenatus*	Percent Incidence of Fungus *Ichthyosporidium hoferi*
Harpswell	9-55	84	0	0	40	0
Ram Island	11-55	58	6	0	44	0
Bailey Island	11-55	28	8	0	46	0
Georgetown Island	11-55	3	0	0	22	0
Boothbay Harbor	11-55	4	6	0	46	0
Christmas Cove	9-55	26	0	0	36	0
Friendship	10-55	0	2	0	28	0
Long Cove	9-55	0	8	0	60	0
Mussel Ridges	9-55	0	4	0	72	0
Vinalhaven	10-55	0	6	0	56	0
Swan Island	11-55	0	24	0	74	0
Mount Desert Island	9-55	0	6	0	50	0
Bois Bubert	9-55	0	6	0	40	0
Jonesport	11-55	0	30	0	20	0
Warmell Bay	11-55	0	22	0	10	1
East Bay	11-55	0	23	0	6	0
Matthews Island	9-55	0	16	0	16	0

Appendix 2. PARASITES OF SARDINE HERRING (Age Group 1)

Location of Sampling	Date	Percent Incidence of Myxosporidia *Kudoa clupeidae*	Percent Incidence of Larval Nematodes (*Anisakis* sp.)	Percent Incidence of Larval Cestodes (Trypanorhyncha)	Percent Incidence of Trematodes *Brachyphallus crenatus*	Percent Incidence of Fungus *Ichthyosporidium hoferi*
Ipswitch Bay	8-56	10	—	8	—	—
Kennebunkport	6-56	10	18	0	36	1
Scarboro	7-56	6	14	0	46	0
Cliff Island	6-56	6	4	2	26	0
Harpswell	7-56	16	10	0	42	0
Bailey Island	6-56	26	4	4	63	0
East Boothbay	7-56	13	20	0	14	0
Christmas Cove	6-56	10	28	0	42	0
Friendship	6-56	2	22	0	50	0
Vinalhaven	8-56	2	14	2	76	0
Smith Harbor	6-56	0	26	0	22	0
Flye Island	6-56	0	12	0	24	0
Frenchboro	6-56	2	24	0	76	0
Mount Desert Island	7-56	3	30	0	60	0
Bois Bubert	7-56	0	46	0	20	0
Jonesport	7-56	0	44	0	20	0
Beals Island	7-56	0	36	0	48	0
Machias Bay	7-56	0	59	0	0	0
Grand Manan	7-56	2	57	0	43	0
Grand Manan	7-56	2	25	0	40	0
St. Andrews, N. B.	7-56	0	46	0	54	0
Bocabec, N. B.	6-56	0	41	0	61	0
Bocabec, N. B.	8-56	0	57	0	52	0
St. Marys Bay, N. S.	7-56	0	36	0	32	0

Appendix 3. PARASITES OF MATURE HERRING 1955

Location of Sampling	Date	Percent Incidence of Fungus *Ichthyosporidium hoferi*	Percent Incidence of Larval Cestodes (Trypanorhyncha)	Percent Incidence of Larval Nematodes (*Anisakis* sp.)	Percent Incidence of Trematodes *Brachyphallus crenatus*
Newport, R. I.	12-55	3	40	23	—
Cultivator Shoals	9-55	2	16	30	10
Provincetown, Mass.	5-55	—	—	18	—
Gloucester Middle Bank	9-55	2	22	35	5
Isle of Shoals	10-55	3	2	20	18
Seguin Island	10-55	—	—	43	—
Matinicus Island	10-55	—	9	36	17
Grand Manan Island	3-55	—	1	35	15
Digby Neck, N. S.	8-55	1	—	—	—
Yarmouth, N. S.	8-55	3	1	48	12
Shag Harbor, N. S.	8-55	12	—	—	—
Lockeport, N. S.	8-55	2	—	—	—
Liverpool, N. S.	8-55	3	—	—	—
Lunenburg, N. S.	8-55	4	—	—	—
Halifax, N. S.	8-55	6	—	—	—
Northumberland St.	5-55	15	—	—	—
Carleton, P. Q.	5-55	70	—	—	—
Newport, P. Q.	8-55	66	—	14	50
Paspebiac, P. Q.	5-55	41	—	—	—
Grand River, P. Q.	5-55	20	—	—	—
Fox River, P. Q.	5-55	11	—	19	14
River Madeleine, P. Q.	5-55	33	—	—	—
Bay of Islands, Newf.	5-55	4	—	24	—

Appendix 4. PARASITES OF MATURE HERRING 1956

Location of Sampling	Date	Percent Incidence of Fungus *Ichthyosporidium hoferi*	Percent Incidence of Larval Cestodes (Trypanorhyncha)	Percent Incidence of Larval Nematodes (*Anisakis* sp.)	Percent Incidence of Trematodes *Brachyphallus crenatus*
Block Island, R. I.	12-56	—	44	10	—
Provincetown, Mass.	4-56	—	4	28	38
Provincetown, Mass.	5-56	2	6	12	34
Georges Bank	9-56	3	14	36	—
Cultivator Shoals	7-56	2	18	36	28
Gloucester	9-56	2	19	49	—
Machias Bay	7-56	—	5	24	36
Trinity Ledges, N. S.	8-56	2	—	—	—
Wedgeport, N. S.	8-56	1	—	—	—
Ingomar, N. S.	8-56	2	—	—	—
Halifax, N. S.	8-56	4	2	64	22
Shediac, N. B.	5-56	10	—	—	—
Caraquet, N. B.	6-56	24	—	—	—
Grand River, P. Q.	6-56	25	—	—	—
Grand River, P. Q.	5-56	—	—	—	—
Cloridorme, P. Q.	6-56	22	—	18	12
Crand Vallee, P. Q.	5-56	14	—	—	—
Fortune Bay, Newf.	8-56	4	—	94	—

Appendix 5. PARASITES OF BAY OF FUNDY HERRING

Location of Sampling	Date	Percent Incidence of Myxosporidia *Kudoa clupeidae*	Percent Incidence of Larval Nematodes (*Anisakis* sp.)	Percent Incidence of Larval Cestodes (Trypanorhyncha)	Percent Incidence of Trematodes *Brachyphallus crenatus*	Percent Incidence of Fungus *Ichthyosporidium hoferi*
Matthews I.	9-55	—	16	—	16	—
Warmell Bay	11-55	—	22	—	10	1
East Bay	11-55	—	23	—	6	—
Beaver Harbor, N. B.	12-56	—	42	—	6	—
Blacks Harbor, N. B.	1-56	—	44	—	16	—
Deadmans Harbor, N. B.	1-56	—	58	—	6	—
Seelys Cove, N. B.	1-56	—	64	—	2	—
The Wolves, N. B.	1-56	—	76	—	10	—
Maces Bay, N. B.	2-56	—	74	—	6	—
Pocologan, N. B.	3-56	—	64	—	4	—
St. Andrews, N. B.	5-56	—	45	—	30	—
St. Andrews, N. B.	5-56	—	16	—	32	—
St. Andrews, N. B.	5-56	—	46	—	34	—
Bocabec, N. B.	6-56	—	40	—	60	—
Bocabec	8-56	—	57	—	52	—
St. Andrews, N. B.	7-56	—	46	—	54	—
Bocabec, N. B.	8-56	—	48	—	12	—
Blacks Harbor, N. B.	9-56	—	48	—	12	—

Evolution and Distribution of the Coregonids[1]

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ABSTRACT

Increased knowledge of the morphological and physiological plasticity of the coregonids has minimized the significance of conflicting morphological data that have retarded the development of an evolutionary theory. Of the four phyletic lines recognized through world-wide studies, *Coregonus* originated in the lake and stream area of northwest Eurasia, *Stenodus* and *Prosopium* evolved in the rivers of Siberia and northwest America respectively, and *Leucichthys* became differentiated in the lake-studded area of northeast America. Isolation and range extension were facilitated by events of the Pleistocene epoch. Inter-continental exchange most likely took place in the Bering Strait region. Representatives of each group in its area of origin are highly variable. Range extensions of each group are characterized by lesser morphological variability and at the extremes only one or two relatively stable species remain.

For many decades the complex nature of the coregonids has confounded taxonomists who have sought an adequate system of describing them. The frustrated efforts of early workers caused many of them to feel that conventional taxonomic procedures were inadequate for the description of this group. In recent years the investigators of the coregonids have not depended so strongly on classical morphometry but have placed greater emphasis on sound reasoning and experimentation.

The coregonids are characterized by a high degree of environmentally controlled morphological (Hile, 1937) and physiological (Frey, 1955) plasticity and, due to their recent origin in geologic time, resemblance is close among forms of the different phyletic lines. Svärdson (1945, 1949–1953), through chromosome studies and transplantation experiments, has demonstrated some of the genetic and environmental bases that underlie the high degree of plasticity. This positive evidence of the high degree of variability that exists among the coregonids reduces the significance of much of the conflicting morphological data that have long retarded the development of an overall theory of coregonid evolution, making the present discussion possible.

The first descriptive work on coregonids was done in Europe where the single genus *Coregonus* was established to include all known coregonids of that area. As knowledge was subsequently gained of the coregonids throughout their circumpolar range, four general groups were recognized and have been described as genera: *Coregonus*, (*Artedi*) Linneaus (1738); *Stenodus*, Richardson (1836); *Leucichthys*, Dybowski (1874); and *Prosopium*, Milner (1878). The four genera have long been used to depict the natural phyletic lines of the coregonid complex.

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In Europe, however, where nearly all coregonids belong to the genus *Coregonus* (*sensu stricto*), a single genus is still used for all forms except *Stenodus*. Some workers in other areas have combined two or more of the genera for various reasons so that the problem of the generic standing of the four basic coregonid groups is still under debate.

The problem of generic standing is not, however, germane to the present discussion which is concerned only with origins, evolutionary development, and distribution. A review of the complicated controversial, and often confusing literature on coregonid taxonomy is, therefore, unnecessary. The reality of the four basic groups is, nevertheless, undeniable and I shall accordingly for convenience, apply to them the generic names that have been commonly accepted by investigators in North America.

The range of each coregonid genus has a "nucleus area" where the representatives occur in a wider variety of environments and forms, and where they show a higher degree of plasticity than elsewhere. For *Coregonus* this area is northwest Eurasia, for *Prosopium* northwest America, and for *Leucichthys* northeast America. Although *Stenodus* has been less completely studied, it appears that the "nucleus area" where it occurs in greatest diversity must be in Siberia (Dymond and Vladykov, 1934). The environmental preference (lake or stream) of each genus over its entire range tends to match the predominant environment where it is represented in its greatest variety of forms. This relationship strongly suggests that the "nucleus areas" are the localities in which the several genera differentiated from a common progenitor.

The *Coregonus* group which originated in northwest Eurasia, an area with an abundance of suitable lakes and many cold streams, is found throughout its range mostly in lakes, but occurs also in many streams particularly in the cooler northern regions. *Stenodus* and *Prosopium* differentiated in Siberia and northwest America, respectively, where rivers predominate; both are thought of as river forms because of their preference for rivers elsewhere in their ranges, although they also occupy some lakes. The *Leucichthys* group that originated in the flat, lake-studded area of northeast America shows a strong preference for ake habitats over its entire range. This similarity between the habitat preference of each group and the predominant environment of its area of origin suggests that primary divergence of the groups may have been a process of adaption to different environments.

The northern, circumpolar distribution of the cold-stenothermic coregonids closely follows the limits of the area strongly influenced by cooling climate and glacial ice during the Pleistocene epoch. Changes in the quantity and temperature of water and the advance and recession of ice sheets during the Pleistocene must have had a tremendous effect on the distribution of coregonid fishes.

It is possible that the progenitor of coregonids was not unlike *Stenodus*, which bears a closer resemblance to the salmonids than do other coregonids because its teeth are least reduced in size and its members have an inclination to ndergo extensive migrations. The migratory tendency of a *Stenodus*-like progenitor, with a preference for extreme northern environments characteristic of he present-day *Stenodus*, could have resulted in a circumpolar distribution of this form prior to the Pleistocene. This ancestral form must have been a well-defined yet plastic member of the fish fauna of that time, particularly in its habitat preference. During the first glacial period (Nebraskan-Günz) the extension of cold-water environment and the forced evacuation of certain areas caused by the encroachment of ice sheets brought about a southerly extension of the range of this form. During the subsequent interglacial time (called Aftonian in North America), it would have survived in many southern environments where populations developed to fit the general conditions of the different segments of its range. Thus lake forms evolved in the lake region of northeast America, river forms in northwest America and Siberia, and lake and stream forms in northeast Eurasia. These four regions are the "nucleus areas" of the present genera. During the estimated 200,000 years of the warm Aftonian interglacial period basic differences developed among the representatives of the four areas. The divergence must have been primarily physiological as morphological differences among the basic groups are limited even today. Although the divergent characteristics that separated the four groups may have been small—even superficially insignificant—they were great enough for the groups to maintain their identities in spite of mixing that took place during later glacial and interglacial periods. With such persistent separation there is little probability that these phyletic lines will ever coalesce.

The present distribution of each of the four genera that differentiated early in the Pleistocene must have come about as the result of processes related with subsequent glaciation. The onset of a glacial period with its increased precipitation and cooling climate would extend suitable coregonid habitat. The advance of the several ice sheets would force movements into new waters and cause a mixing of the fish from different areas. As the sheets later receded the coregonids followed, again bringing adjacent groups together. This process repeated during succeeding glacial periods could have been an important agent in extending the ranges of the four groups to approximate the present distribution.

Although this discussion of the evolution and distribution of the coregonid genera has been given in terms of the entire Pleistocene, it is not inconceivable that the process might have been completed in a shorter time. Certainly, if the coregonids always had the high degree of plasticity that they now exhibit, differentiation could have taken place more recently. The exact timing of these geological and biological events is not, however, of immediate importance. Of much greater significance is a reasonable description of the sequence of occurrences that must have taken place to bring about the present coregonid complex. This description, if properly framed, can serve as a basis for understanding and adequately describing present-day forms.

The paths of movement that were probably followed by the four basic groups in attaining their present distribution are illustrated schematically in Fig. 1. The Bering Strait region appears to be the most likely site for an exchange between continents. Although the Bering Strait may have sometimes been a salt-water barrier, it was non-existent at times during the Pleistocene. Furthermore, coregonids of all four genera occur in brackish water in that region (Walters, 1955) and some forms can tolerate high salinities. Thus the transfer of coregonids between Asia and North America presents no problem.

The assumptions as to avenues of dispersal (Fig. 1) are substantiated by the characteristics of each genus over its range. *Leucichthys*, for instance, is represented by a variety of highly plastic species in northeast America where it originated. Moving westward from this area, the variety and plasticity of forms in this group decreases and at the extreme end of its range in northwest Europe it is represented by the relatively stable *Coregonus* [*Leucichthys*] *albula*. Although the Europeans include this form in the genus *Coregonus* (subgenus *Argyrosomus*) because of its morphometric similarities with some other members of the restricted genus *Coregonus*, contacts with coregonid workers in Europe revealed that the general features (sight recognition) so clearly separate *C. albula* from other local *Coregonus* that it is not considered in discussions of systematic problems of the European coregonids. Investigators in Europe and North America have recognized *C. albula* to be closely similar to the lake herring or cisco (*L. artedi*) of North America. Unquestionably both are representatives of the same phyletic line. The progenitor of the many *Leucichthys* forms that now have a nearly circumpolar distribution most likely resembled the lake herring. The lake herring lives in the widest variety of habitats in the "nucleus area" of its genus. Such an adaptable form would be best suited to survive in the varied environments encountered in range extension. Also, most members of the *Leucichthys* group found outside of the Great Lakes area, where the widest variety of forms are found, resemble *artedi* more closely than any other species within the area.

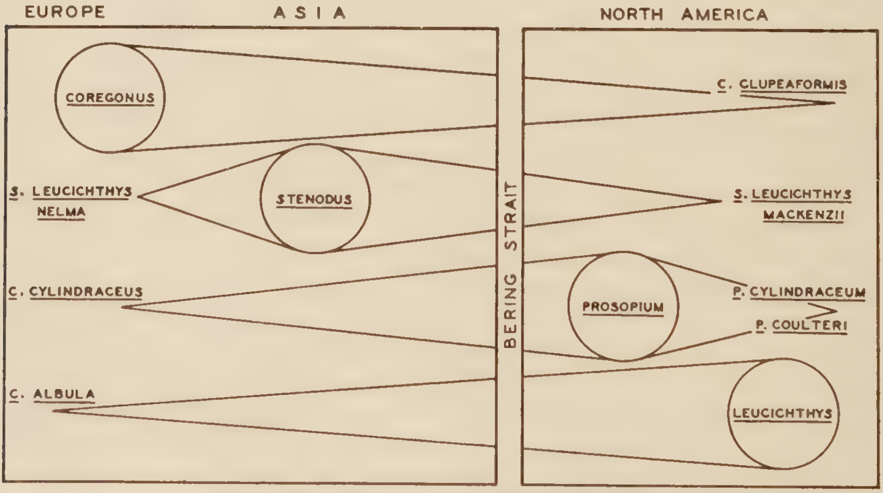

FIG. 1. Schematic diagram of the development areas and dispersal routes of coregonid genera.

The distribution of the *Coregonus* group follows the pattern of *Leucichthys* but in reverse (west-east) direction. From a center in north and central Europe where varied and highly plastic forms are found the variety and plasticity decrease in the easterly extension of the range. At the extreme eastern limit this genus is represented by one relatively stable species, *C. clupeaformis*. The form that contributed most to present-day species of *Coregonus* may have resembled *C. lavaretus* as this fish seems to be highly adaptive and is similar to most members of its group outside Europe. The designation of a form most likely to fill this position would, however, be best suggested by someone who has worked extensively with coregonids in Europe and Asia.

The *Prosopium* group has extended its range to both the east and the west. From a center in the western mountains of North America the variety of forms diminishes in each direction. The genus is represented by two relatively stable species (*P. cylindraceum* and *P. coulteri*) in the eastern extremity of its range in northeast America and by one species (*C.* [*Prosopium*] *cylindraceus*) at the western extremity in northern Russia. *P. cylindraceum*, the most adaptive species of this group, probably resembles the common ancestral form.

The lack of adequate information about *Stenodus* from what must be its "nucleus area" in Siberia makes generalization difficult. *Stenodus* appears, however, to be more stable than other coregonid groups although further study may show that the characteristics of variability in different parts of its range resemble those of the other genera.

These views on the evolution and distribution of the four phyletic lines of coregonids have been described in a greatly simplified form. From a morphological standpoint a number of irregularities may exist among the several genera. These are to be expected in a group with the morphological and physiological plasticity of the coregonids. During the process of range extension, members of each phyletic line were undoubtedly subjected to environmental pressures that may have promoted ambient morphological developments in local populations. Isolated populations of one genus may have, through retrogressive or parallel development, acquired one or more characteristics common to most members of another genus. Despite this "concealing" type of development, experienced investigators have been able to recognize through other characteristics the true group to which the aberrant population belongs. Inconsistencies of this type do not, therefore, detract seriously from the validity of the ideas expressed here.

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LIMNOLOGICAL SURVEYS OF THE GREAT LAKES—EARLY AND RECENT

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ABSTRACT

Early explorations on the Great Lakes were concerned largely with things easily collected or observed—common organisms, water levels, surface temperatures . . . Even when more scientific studies were undertaken, they were at first scattered and small-scale. Effective surveys became possible only through inter-agency cooperation which permits a pooling of facilities, staff, and equipment. Expansion of limnological research on the Great Lakes has been rapid in later years and the outlook for the future is good.

The Great Lakes of east-central North America have practically been bypassed during the formative period of the relatively young science of limnology. It is not difficult to understand why this largest fresh-water lake system, with its major bodies ranging from the largest to the thirteenth-largest fresh-water lake in the world, has always been looked upon with great interest. It is surprising, however, that these lakes, located in a rich and densely populated section of the earth, have been so little explored until recent years. Problems of obtaining staff, specialized equipment, and vessels for operating on the lakes long have impeded major investigations. In recent years, however, increased interest in fishery problems and the expanding use of the lakes as a source of water, and for navigation and waste disposal have created the economic pressure required to bring about more comprehensive studies than have previously been possible.

The large size of the Great Lakes has imposed new operational requirements in the field of limnology and has necessitated some modification of concepts which have been largely formulated from studies of smaller bodies of water. Ideas have been borrowed from the oceanographer along with equipment with which to explore them. Because of their confined nature as compared with the oceans, many oceanographic concepts are not fully applicable, and new hypotheses have to be developed to interpret and describe properly the limnological features of these large inland lakes. This situation in turn may stimulate new ideas in the field of limnology as a whole, for what happens in the Great Lakes on a conspicuously large scale may also be occurring in smaller bodies of water in proportion.

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EARLY EXPLORATIONS

The early scientific studies of the Great Lakes gained momentum in the first quarter of the nineteenth century (see Leverett and Taylor, 1915) when geologists and cartographers started compiling information on the size, configuration, and geological structure of the lake basins. These basic records on the morphometry of the lake basins provided a useful background for the early limnological observations.

Although their curiosity ran high, early investigators of the Great Lakes were limited in their facilities, equipment, and techniques and studied only things that were easy and simple to measure or collect. Water-level fluctuations attracted much early attention (Bigsby, 1829; Sharpe, 1831) because changes were often great and sometimes very rapid. Earliest observations of unusual water-level fluctuations were passed on as stories by early settlers and were eventually recorded in early reviews (Whittlesey, 1875). A number of these observations were probably based upon "tidal waves" such as the one that occurred in Lake Michigan in 1954 (Ewing, Press, and Donn, 1954). The recognition of the regularity of water-level fluctuations stimulated studies to determine the periodicity and resolve the question of lunar influence (Ruggles, 1843; Whittlesey, 1859). These inquiries demonstrated that the regular periodicity of prominent fluctuations could not be related to influences of the moon. It was concluded that the "tides" may result from planetary influences, modified or at times dominated by winds. A long-term study in Lake Michigan (Graham, 1861) clearly demonstrated a lunar tide of 0.15 to 0.20 foot which is generally overshadowed and hidden by seiche action. The long-term seasonal and annual changes in water level also drew the attention of early investigators (Dewey, 1859; Whittlesey, 1860) who started a series of records that have provided a base for better understanding and even predicting seasonal and annual lake levels.[1]

Water temperature was easy to obtain, and it received some early attention (Dewey, 1838, 1839). Temperature was not given any appreciable study, however, until after the Negretti-Zamba type of reversing thermometer was put into use during the last quarter of the nineteenth century (Drummond, 1890; Coleman, 1922). Records of subsurface temperatures that were possible with the reversing thermometer opened an entirely new field of speculation as to the circulation and thermal structure of the lakes. Of particular interest were records of summer temperature in deeper sections of the lakes where the water was less than 4°C. This phenomenon was at first puzzling but later it was adequately explained as an effect of pressure on the temperature of maximum density of water (Wright, 1931). Although temperature differences between the surface and bottom were great enough for the formation of a thermocline, few vertical records were satisfactory enough to detect it. Records available up to the early 1930's led to the impression that: ". . . regional thermoclines occur at certain times and places, in the other [than Lake Erie] Great Lakes," and ". . . in such waters there is no continuous thermocline extending from one shore to the other, as is the case in the inland lakes . . ." (Welch 1935, p. 56). With the advent of the bathythermograph in the early 1940's which provides a complete thermal record form surface to bottom it was discovered that themoclines are a regular feature of the deeper areas of the Great Lakes (Church, 1942, 1945; Hachey, 1952; U. S. Fish and Wildlife Service records, unpublished).

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[1] Monthly lake-level reports and news releases issued by the Lake Survey, U.S. Army Corps of Engineers, Detroit, Michigan.

The collection of biological information on the Great Lakes was probably hampered by difficulties of getting suitable boats for making observations and obtaining samples. Some of the earliest records of invertebrate life in the Great Lakes (about 1870) were based on the contents of "whitefish" (probably *Leucichthys* spp.) stomachs (Hoy, 1872). Dredging studies initiated during this period (Smith, 1871, 1874; Stimpson, 1871) gave a more adequate picture of deep-water life and provided information on bottom materials at various depths. Difficulty in obtaining a means of getting onto the lake also limited plankton collections which were often restricted to inshore areas (Forbes, 1891).

EARLIER LIMNOLOGICAL SURVEYS

Perhaps the earliest organized survey party to record general limnological information on the Great Lakes was the group headed by Louis Agassiz on Lake Superior in 1848. This party of naturalists and students traveled by canoe from Sault Ste. Marie, Michigan, to Fort William, Ontario, collecting and observing whatever they could. The narrative of the trip recorded by J. Elliot Cabot (Agassiz, 1850) includes a number of general remarks on the relative temperature, color, and transparency of the water, and on water-level fluctuations. The party measured transparency by lowering a tin cup which was seen to a depth of 42 feet. This group made no great contribution to our knowledge of Great Lakes limnology but their effort did represent a start in organized surveys of the lakes.

The increased use of the Great Lakes for navigation, as a source of drinking water, and the conflicting use as a depository for domestic and industrial wastes created a need for more knowledge of water movements (Clark, 1892). To satisfy this need the U. S. Weather Bureau and the Meteorological Service of Canada released nearly 5,000 drift bottles throughout the Great Lakes over a 3-year period (1892-1894). Data from 672 bottles that were recovered were used by Harrington (1895) to establish his classical surface-current charts of the Great Lakes. These charts are open to serious criticism both in the manner in which they were compiled and in the light of subsequent information. Although Harrington mentioned the varying nature of water movements and the complex of factors other than currents that may influence the movement of a drift bottle, the evidence suggests that in preparing his charts he relied more on general assumptions as to factors creating water movement than on his relatively scanty returns. These assumptions were that water tends to flow toward the outlet of a lake, that prevailing westerly winds create primary currents moving from west to east, and that when water moves in the direction of an inadequate outlet (or none at all) it must return in another current in an opposite direction. Harrington was influenced further by a firm belief that primary currents are persistent in direction but varied in velocity, and that secondary currents vary little in direction but greatly in velocity.

Even before Harrington's study, Clark (1892), from observations on Lake Ontario, concluded, "With the opinion that there are any regular, constant, well-defined lake currents, I feel inclined to disagree." In summarizing results of returns of drift bottles from Lake Erie in the early 1930's Wright (1955) observed: "Thus, while Harrington's data suggest great constancy in direction of currents, the data of this study emphasize their inconsistencies . . ." Highly variable water movements in Saginaw Bay also were demonstrated by the charts of the Michigan Stream Control Commission (Adams, 1937).

The strongest evidence of irregularity in currents of the Great Lakes, including on occasion circulation patterns directly opposite to those shown by Harrington's charts, has come from a study of Great Lakes Fishery Investigations, U. S. Fish and Wildlife Service, in Lake Michigan in 1954 and 1955. In this operation 6,300 drift bottles and other drift missiles were released at 5-mile intervals (usually 20 released at one location) over several east-west transects at 3- to 6-week intervals from April through November. Although analysis of the data is not yet complete, it has been demonstrated clearly that the major surface-current structure of Lake Michigan can change greatly over a 3-week period. These analyses are based on a better than 60-percent recovery. Sometimes recoveries from releases of one day along a single transect nearly equal the number that Harrington had for his entire study. Although some general tendencies in direction are apparent, the concept of a high degree of stability in surface-water movements of the Great Lakes, as implied by Harrington's discussion and charts, is not supported.

Jacob Reighard might be considered the originator of organized limnological research on the Great Lakes. He pointed out that individual investigators working separately and with limited facilities accomplish little more than the solution of small local problems (Reighard, 1894). Recognizing that little was known about the Great Lakes, Reighard (1899) called for general basic research that would produce in advance information that could be used to solve problems as they arise. Acting on these views, he organized the first cooperative research project on the Great Lakes. He established a laboratory on Lake St. Clair in the summer of 1893 under sponsorship of the Michigan Fish Commission in space supplied by a local citizen and with laboratory apparatus loaned by the University of Michigan. Reighard and five other investigators of various specialties in aquatic biology, who worked without compensation, joined their efforts to study the lake and its biota. In 1894 H. B. Ward (Ward, 1896), in Reighard's absence, headed a similar cooperative group under the same sponsorship that studied the Little Traverse Bay region of Lake Michigan. Although both survey groups were limited to small boats and the occasional use of steam tugs in collecting trips, they made notable contributions to knowledge of conditions in the lakes and their flora and fauna. Reighard's surmounting limitations of expense, personnel, and equipment through the organization of cooperative investigational unit initiated a procedure that has since been a means of carrying out projects larger than would be possible for a single organization. It thus heralded a new and more productive era of limnological research on the Great Lakes.

The drastic changes in fish populations and the conspicuous insurge of domestic and industrial wastes into Lake Erie aroused much public concern in the early 1920's. This interest led to a series of investigations which together constituted a survey of Lake Erie (Wright, 1955) more comprehensive than any conducted on the other lakes. The Ohio Division of Fish and Game (later the Ohio Division of Conservation) started a program in 1926 to study aquatic conditions in western Lake Erie. This study was enlarged through the cooperation of the U. S. Bureau of Fisheries in 1929 and 1930.

An intensive limnological survey of the eastern end of Lake Erie was conducted in 1928 by the State of New York (Fish, 1929; Moore, 1929) through the cooperative efforts of the New York Conservation Department, the U. S. Bureau of Fisheries, the Province of Ontario, the City of Buffalo, and the Buffalo Museum of Science.

Although the two groups of cooperating agencies worked independently in the west and east ends of the lake, their combined studies represent a comprehensive hydrographic and biological survey of Lake Erie. A most notable advance of these surveys was the initial use on the Great Lakes of vessels especially equipped for hydrographic studies.

Another major cooperative venture was started on Lake Michigan in 1930 through the joint efforts of the U. S. Bureau of Fisheries, the states of Michigan and Wisconsin, and four fish-net manufacturers. Although the survey was concerned primarily with problems related to the fisheries for lake trout *(Salvelinus namaycush), and chubs (Leucichthys* spp.), extensive limnological data were collected (Ahlstrom, 1936; Deason, 1932, 1936; Eggleton, 1936, 1937; Wright, 1931). Some of the records even now remain to be analyzed.

Our understanding of the thermal structure of the Great Lakes was advanced greatly by the development of the bathythermograph. Church (1942, 1945) was the first to use this instrument extensively in the Great

Lakes. His temperature survey of Lake Michigan in which he drew upon the assistance of lake ferries and the U. S. Coast Guard vessels gave the first positive evidence of the complexity of the temperature conditions in deeper waters of the lakes.

Although not a survey-type program, the work conducted through the years 1896-1955 at the Franz Theodore Stone Laboratory (Langlois, 1949), considered as a whole, has been an outstanding contribution to our knowledge of the limnology of western Lake Erie. Many researches have covered thoroughly various features of this area. Somewhat similar have been the long-term contributions of the Great Lakes Fishery Investigations of the U. S. Fish and Wildlife Service (Bureau of Fisheries prior to 1940). This group has compiled many observations of limnological conditions on the lakes which individually may be small but collectively constitute a broad background of material. A series of studies conducted from 1911 to 1914 at the Great Lakes station of the Biological Board of Canada developed extensive information on the fauna, flora, and hydrographic conditions of Georgian Bay, Lake Huron (Prince, 1915). These along with many other individual efforts such as Daily (1938); Eddy (1943); and Gottschall and Jennings (1933); have done much to add to our knowledge of the Great Lakes.

Recent and Current Limnological Research

Although a list of individual researches and surveys on the Great Lakes would be impressive, it does not reflect a correspondingly advanced state of understanding of the lakes. Studies have uncovered new questions more rapidly than they have answered old ones. Such a situation must, however, be healthy for it has fostered the creation of new organizations dedicated to Great Lakes research and has invigorated existing ones.

Most recently organized have been: the Great Lakes Commission, established in December 1955, an organization representing six Great Lakes states and dedicated to promote studies that will advance all uses of the Great Lakes; and the Great Lakes Fishery Commission, an international body established in October 1955, whose purpose, in addition to bringing about control of the sea lamprey, is to coordinate fishery and hydrographic research conducted by independent units and to support research activities of its own. Organizations that have been active in recent and current limnological research are mentioned in connection with the work in which they have been engaged.

During the last decade and particularly in the past 5 years Great Lakes research has been progressing at an increasing tempo. Early in this period the University of Western Ontario conducted a local but comprehensive limnological survey of western Lake Erie, the results of which are yet to be published. About the same time the Ohio Department of Natural Resources was increasing its research on the limnology of Lake Erie. The Ohio studies have led to a much better understanding of the general circulation (Verber, 1955), seiches, water temperatures, and climate of western Lake Erie, and some attention has been given to central and eastern parts of the lake. Other studies have dealt with the dispersion of industrial wastes in the lake (State of Ohio, 1953) and surveys of bottom materials, particularly in relation to sand deposits and shore erosion. Since 1953 the work of the Ohio Division of Shore Erosion on Lake Erie has been facilitated by a specially constructed and equipped hydrographic research vessel.

Possibilities for extensive long-term limnological research on the Great Lakes were increased when the U. S. Fish and Wildlife Service launched its research vessel *Cisco* in 1951 (Moffett, 1954). This boat is equipped with many of the latest devices for measuring, recording, sampling, and analyzing limnological features of the lakes. In 1951, the *Cisko* was used to map the bottom materials of Lake Michigan (Hough, 1952). This work led to a revision of the recent pleistocene chronology (Hough, 1955) by introducing the new low-water "Lake Chippewa" stage. In 1952 the vessel operated intensively in Green Bay and made brief exploratory runs into Lakes Huron, Michigan, and Superior; and in 1953 she was used in a general fishery and hydrographic survey of Lake Superior. Although much of the extensive limnological data collected in these years is still undergoing analysis, some data have found use in fishery studies (Eschmeyer, 1956; Smith, 1956). During 1954 a survey was conducted of the southern half of Lake Michigan and similar coverage was made on the northern half in 1955.

The "synoptic survey" was introduced to the Great Lakes in 1953 when the Ontario Department of Lands and Forests sponsored studies in which 5 and 6 boats operated simultaneously once a month during the summer to provide 1-day coverages of Georgian Bay. These surveys were so successful that they led to three synoptic coverages of Lake Huron in 1954 (Ayers, Anderson, Chandler, and Lauff, 1956) through the cooperative efforts of the Ontario Department of Lands and Forests, the University of Toronto, the Great Lakes Research Institute of the University of Michigan, the Michigan Department of Conservation, and the U. S. Fish and Wildlife Service. This type of operation was continued in 1955 when four synoptic coverages of Lake Michigan were made under the principal sponsorship of the Great Lakes Research Institute, and a survey of Lake Erie was made through the cooperative efforts of Ohio State University, the Ohio Department of Natural Resources, the New York Conservation Department, and the Ontario Department of Lands and Forests. Also in 1955, preliminary 1- and 2-vessel surveys were conducted on Lake Ontario by the Ontario Department of Lands and Forests. Thus, the cooperative research program visualized by Reighard is being realized fully some 60 years after he set up his first cooperative laboratory on Lake St. Clair in 1893. In 1956, however, only one cooperative synoptic survey was in progress—a coverage of Saginaw Bay sponsored jointly by the U. S. Fish and Wildlife Service and the Michigan Department of Conservation.

Limnological studies in 1956 are mostly independent ventures sponsored by a number of organizations. The Great Lakes Research Institute is conducting intensive studies of the Mackinac Straits area of Lakes Huron and Michigan. The South Baymouth Laboratory of the Ontario Department of Lands and Forests is continuing periodic measurements of the physical and chemical conditions in South Bay, Lake Huron. Studies of Lake Ontario are being conducted by the Ontario Department of Lands and Forests with a full-time hydrographic research vessel. The Ohio Division of Shore Erosion is continuing its broad studies of circulation patterns and water-level fluctuations in Lake Erie. The U. S. Fish and Wildlife Service, in addition to the cooperative synoptic surveys of Saginaw Bay, has assigned its research vessel *Cisco* to studies of Saginaw Bay, its adjacent waters, and southern Lake Huron.

The major barriers to limnological research of the Great Lakes have indeed been broken. The scale of field operations has reached an all-time high. The greatest amount of data ever compiled on the Great Lakes as a whole is undergoing analysis, and the talent of more investigators than ever before is being directed toward limnological research. Although the future is always uncertain, there is little doubt that the interest and activity in this field will continue to grow.

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Infectious Pancreatic Necrosis in Trout

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Infectious Pancreatic Necrosis in Trout

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Since the report of pancreatic necrosis in young fingerling brook trout, Salvelinus fontinalis, by Wood et al.,[1] an increasing number of outbreaks of this disease have been observed in different parts of the country. Some outbreaks occurred also among small fingerling rainbow trout (Salmo gairdneri). However, diagnosis in rainbow trout has been made only on the basis of gross symptoms, which are characterized as intermittent whirling or corkscrewing of the affected individuals, lack of food in the entire intestinal tract, and the presence of nearly colorless mucus in the more or less distended gut. The flow of bile appears almost completely stopped. Since M'Gonigle[2] did not include histopathological data in his report, there is no absolute certainty that the disease described by him is identical with pancreatic necrosis in trout. However, since the behavior of the diseased trout and the gross symptoms were exactly the same, it is likely that the diseases reported by M'Gonigle and by us are identical.

Histopathological examination of trout from the 1954 outbreak at the Leetown station revealed acute pancreatic necrosis. Necrotic changes in voluntary muscles of the affected fish collected from the outbreaks in 1955 have furnished additional facts, which are here presented, supporting the hypothesis that the agent of this disease may belong to the Coxsackie group of viruses.

Material and Experiments

In the winter of 1955 the disease again affected at the Leetown station fingerling brook trout that hatched simultaneously from two unrelated batches of eggs received from the same sources as those in 1954 (Berlin, N. H., and Bellefonte, Pa.). As in 1954, the disease started first in the Bellefonte trout and was then apparently transmitted to the Berlin group. In the winter of 1956 no trout were hatched from eggs received from the Bellefonte hatchery and no outbreak occurred. The association of pancreatic necrosis with eggs received from the same source may serve as additional evidence of the infectious nature of the disease and its transmission by fish eggs. It is possible that the infective agent survives inside the trout eggs, since the external disinfection of eggs with sodium-*p*-(ethylmercuri)thiophenylsulfonate (Sulfo-Merthiolate) did not prevent the outbreaks of the infection.

In the outbreak which occurred in 1955 the peak of mortalities occurred about Feb. 10 in the Bellefonte trout and about Feb. 28 in the Berlin trout. The highest mortality for a five-day period was 19% in both strains of trout. The total loss calculated from the hatchery mortality records was 62% for the Bellefonte trout and 77% for the Berlin trout. Since routine hatchery mortality records are not very accurate and losses from all other causes are lumped together, the difference between these two figures cannot be considered significant.

Reliable figures have been obtained, however, by observations carried out on especially selected samples of the Berlin brook trout which were transferred to experimental troughs just after the presence of the disease became apparent. Four groups were selected. Groups A and B were taken from troughs in which the disease was causing heavy mortality. In Group C the disease symptoms were just appearing, and Group D was believed free of the disease. The comparative mortality in the four groups is shown in Figure 7. Losses were the lowest in Group D, in which the disease was apparently in the incubating stage during the first 15 days of observation. This fact may serve as support for the observation reported by M'Gonigle[2] that mortalities caused by this disease decrease with the increasing age of the affected trout. It indicates, too, an additional similarity between this condition and the Coxsackie virus group, which is also much more pathogenic to young mice and hamsters,[3-5] with a decreasing pathogenicity as the host's age increases.

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Fish were examined histologically from all four groups on Feb. 17, when the rate of mortality was climbing sharply in the first three groups. Moribund fish from Group A and nonmoribund specimens from Groups B, C, and D were selected. The fish were fixed in Bouin's solution for 24 hours and stored in 65% alcohol. The specimens were small, approximately 1 in. in length, and were embedded whole in paraffin, and longitudinal sections were made of the entire fish. Hematoxylin and eosin and Wolbach's Giemsa variant were used routinely.

Results

Only the moribund fish of Group A (Fig. 1) showed any histological evidence of pancreatic lesions, and all of these specimens were uniformly affected with acute pancreatic necrosis, as previously described.[1]

The fish of this group were affected also by necrosis of the voluntary muscles. The extent of the lesions varied from slight to extensive, but every moribund fish exhibited the lesion in some degree. Over half of the nonmoribund fish from Groups B and C of the infected populations also contained slight muscle necrosis. In these fish, very few muscle fibers were affected, however, and the disease was apparently in the initial stages. The severest lesions in Groups B and C were in a less advanced stage than those in the least affected fish from Group A. In the fish from Group D of the apparently noninfected population, two of six specimens were observed with a single muscle fiber in the first stages of hyaline degeneration.

The necrosis of the striated muscle fibers was segmented in type and resembled that described for Conn.-5 and Ohio-1 viral types.[6] The causative agent in this case was only moderately myopathic, and the lesion was limited to scattered fiber segments. In the severest cases, many more individual fibers were affected but the lesions were not generalized or widespread, as described for the Texas-1 strain.[6] Certain selected muscles exhibited a tendency for earlier involvement, particularly those of the lower jaw and the dorsal muscles of the neck. This was particularly true of the nonmoribund fish from the infected population. In the most advanced lesions, however, the majority of the striated muscles displayed at least a limited number of necrotic fibers.

The degeneration observed in the muscle fibers was a hyaline change similar to Zenker's degeneration. The condition apparently occurred with great rapidity, for only rarely were muscles seen in the early or intermediate stage of hyalinization. Almost invariably all internal detail of the fibers was obscured, and usually great distortion and crumbling of the hyaline masses had occurred. A few nuclear remnants were present, but such debris had often disappeared. There was no mineralization, and the sarcolemma was often intact.

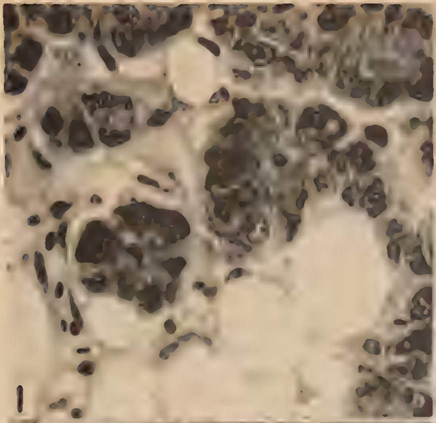
In marked contrast to the sequence of regeneration recorded in mammals, practically no inflammatory or regenerative changes were observed. An occasional polymorphonuclear leukocyte was the extent of the inflammation. There was no "sarcolemmal tube" formation and few sarcoblastic slips. The picture was rather strikingly that of a normal muscle mass surrounding completely degenerated individual fibers, with only a barely perceptible reaction of the host tissue.

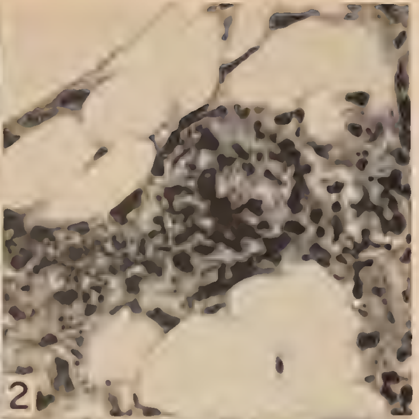
The livers of all three groups were moderately fatty, but there were no pathological changes. The hearts, central nervous systems, and adipose tissues were without distinguishing lesions.

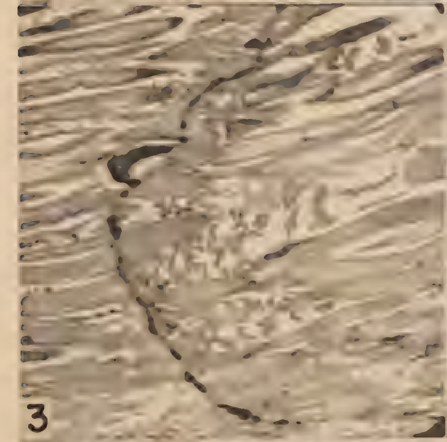
Comment

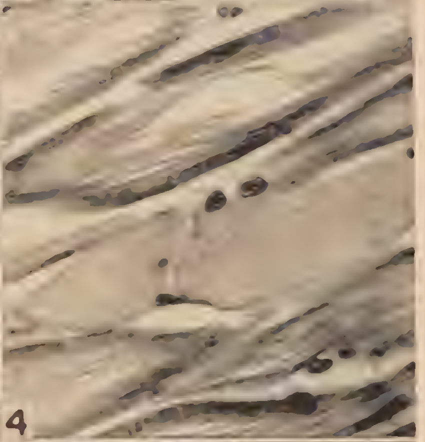
Certain Coxsackie viral strains and the virus of mumps are the only known viral agents with the capacity to produce necrotizing pancreatitis.[6-8] The high incidence of pancreatic lesions in very young brook trout concurrent with necrosis of the striated musculature presents the interesting possibility that a relationship exists between the causative agent of this disease and the viruses of the Coxsackie group.

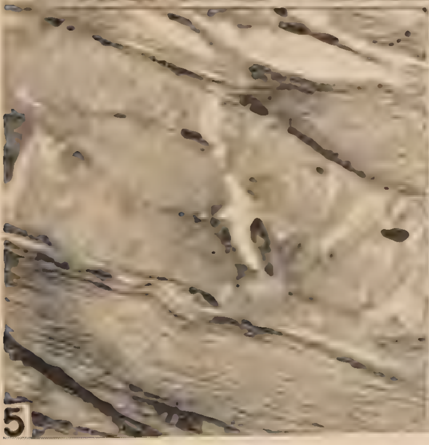
The lesions in fish bear a striking resemblance to those described in mice. The











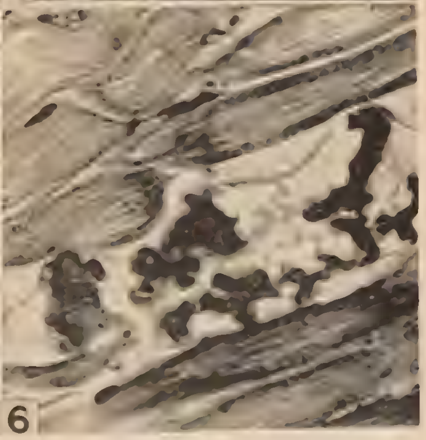


Fig. 1.—Normal acinar tissue of the brook trout pancreas from noninfected fish of Group A. Hematoxylin and eosin; × 475.

Fig. 2.—Acinar tissue in an advanced stage of necrosis from moribund fish of Group C. Hematoxylin and eosin; × 475.

Fig. 3.—Severe muscle necrosis in the caudal peduncle. Note the lack of inflammatory response. Hematoxylin and eosin; × 100.

Fig. 4.—A comparatively early stage of the hyaline degeneration. The surrounding fibers are normal. Hematoxylin and eosin; × 475.

Fig. 5.—The hyalinized bundles are beginning to crumple and fragment. Hematoxylin and eosin; × 475.

Fig. 6.—An advanced stage of crumpling and distortion. No inflammatory response has occurred. Hematoxylin and eosin; × 475.

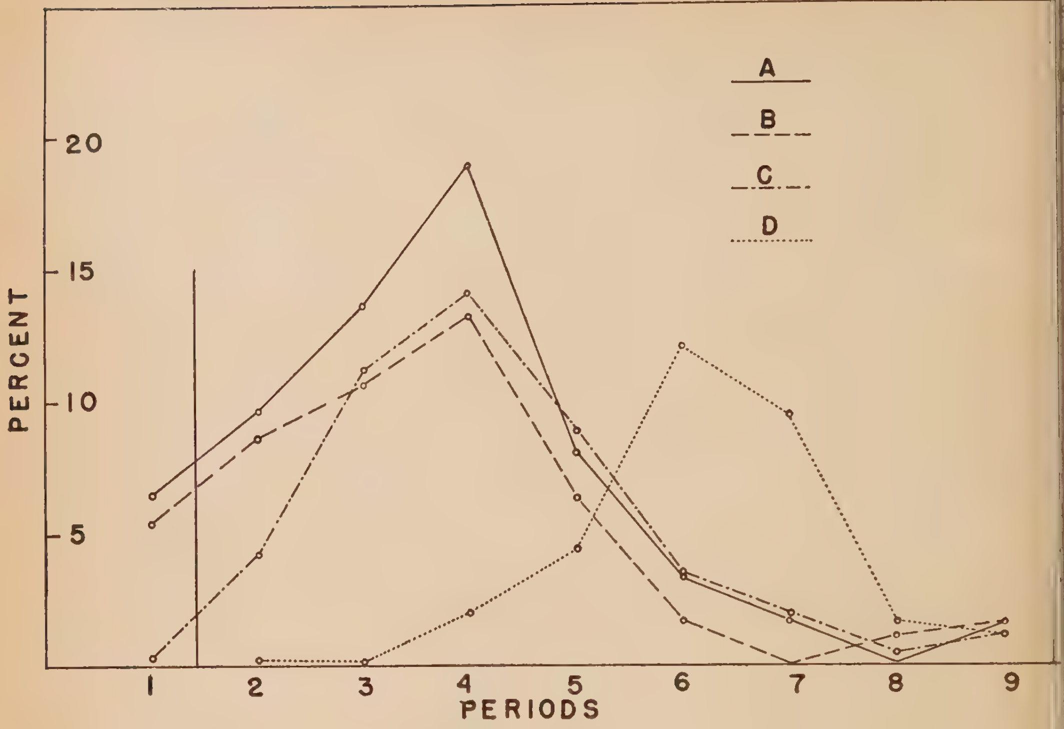


Fig. 7.—Percentage mortalities per five-day periods, starting on Feb. 10, 1955. The total losses, presented as percentages, during the time the records were kept (Feb. 10 to March 26, 1955) were as follows: *A,* 48; *B,* 40; *C,* 38; *D,* 28. Trout in Lots A and B were taken from hatchery troughs in which the disease was in full progress. In Lot C the disease just started, and those in Lot D were believed to be free from the disease on Feb. 10. The vertical line indicates the time (Feb. 17) at which specimens were removed for histopathological examination.

absence of inflammatory and regenerative changes in the muscle lesions is the most outstanding difference. This failure of repair may be due to the rapid death of moribund fish. Little is known of the processes of inflammation and repair in the salmonids, however, and the course of events may be much slower for this species. The occurrence of myopathy in nonmoribund fish from infected populations which had not yet developed pancreatic lesions suggests that the muscle lesions precede the pancreatitis. The very slight incidence of individual muscle fibers in early stages of hyalinization in fish from noninfected populations may indicate the very first stages of the disease or be evidence that the virus is endemic in these nonmoribund populations.

Our studies have not progressed to the point where we can successfully initiate the disease under laboratory conditions and observe the developing pathogenesis. It is possible that liver, heart, and brain injuries do develop which have so far been undetected.

Histopathological studies with fish have been in progress at the Salmon Nutrition Laboratory only since mid-1953. During this period, however, diseased fish have been received from all parts of the United States and several foreign countries for histological examination. Not infrequently severe noninflammatory myopathy of the type described in this paper has been observed. Since much of this material was fixed by untrained field personnel and was not accompanied by control specimens, the significance of the observations was open to question. There is, however, a growing body of evidence that fish are susceptible to or carriers for an infective agent or agents which produce lesions similar to those deribed for the Coxsackie viruses. Since little is known of the natural hosts of ese organisms, the present observations ould be of considerable interest.

Summary

A hyaline degeneration of the striated uscle fibers was observed in fingerling rook trout suffering from a disease de- cribed by us previously as infectious pan- reatic necrosis. The histopathological hanges in the pancreas and striated uscles, the infectious character of the isease, and the considerable susceptibility f a very young trout suggest the possibility hat the disease may be caused by an agent aving the characteristics of the Coxsackie roup of viruses.

Microbiological Laboratory, Fish & Wildlife Service (P. O. Kearnysville).

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STAFF AND FUNDING

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Filter Paper Electrophoresis of Serum Proteins from Sharks

THEODORE J. STARR AND WALTER FOSBERG

VARIOUS investigators have shown that electrophoretic techniques (McDonald, 1955) are well suited for characterization of serum protein abnormalities in man (Mackay and Volwiler, 1954) and in cattle (Bradish *et al.*, 1954). However, it is difficult to find a basis of comparison of blood protein patterns found by research groups using different apparatus and procedures (Deutsch and Goodloe, 1945; Moore, 1945; and Deutsch and McShan, 1949).

ese investigators used the Tiselius-type ctrophoretic apparatus (Taylor, 1953) to amine sera and plasma proteins of various ammals, birds, and vertebrates. They showed at the characteristic pattern of each species reproducible and that the differences between ecies, in respect to both quantity and presence absence of components, is significant. In ldition they emphasized that only patterns tained under similar experimental conditions ere comparable.

Recently, Cremer and Tiselius (1950) have own that the components of serum protein uld be separated effectively by filter paper ectrophoresis. Some advantages of filter aper electrophoresis over the Tiselius methods re the smaller sample required, lower cost of quipment, and ease of use. Gleason and Fried-erg (1953) used filter paper apparatus to xamine the serum proteins of small animals. rilhon (1953) examined two eels, a carp, and dogfish. Dessauer and Fox (1956) examined bout 1200 plasma protein patterns of members f the orders *Amphibia* and *Reptilia*.

In this investigation the blood serum protein atterns of four species of sharks were studied sing paper electrophoretic techniques. It is oped that further studies along these lines ill be of value as a phylogenetic tool and for comparative biochemical studies of marine organisms.

METHODS

Six male sharks were caught August, 1956 with a seine in the Gulf of Mexico along the shore of Galveston, Texas. The sharks were identified (Tee-van, 1948) by Mr. E. L. Arnold of this laboratory. They represented two specimens of *Scoliodon terrae-novae* or sharp-nosed shark, each 15 in. total length; two specimens of *Aprinodon isodon*, each 19 in. total length; one specimen of *Sphyrna diplana* or hammerhead shark, 18 in. total length; and one specimen of *Sphyrna tiburo* or bonnet-head shark, 19 in. total length. The fish were brought to the laboratory within one hour and appeared dead on arrival. Their hearts were exposed (all were beating) and cardiac punctures were made with glass pipets. Only one puncture was made per fish in order to avoid dilution of each blood sample with body fluids. Approximately 2 to 5 ml. of blood from each shark were placed into separate test tubes. After several hr. at room temperature (24°C–26°C), the expressed serum was removed from the clot by decanting. Serum samples were centrifuged at 8,000 rpm at 4°C. for 5 min. Aliquots of the straw-yellow sera were analyzed immediately.

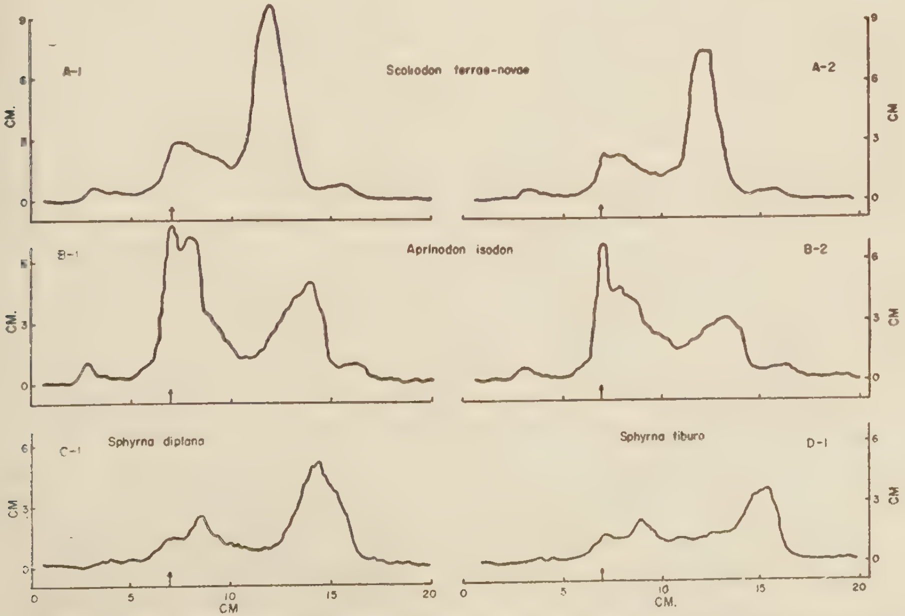

Fig. 1. Filter paper electrophoretic patterns of shark serum samples. Arrow indicates starting line.

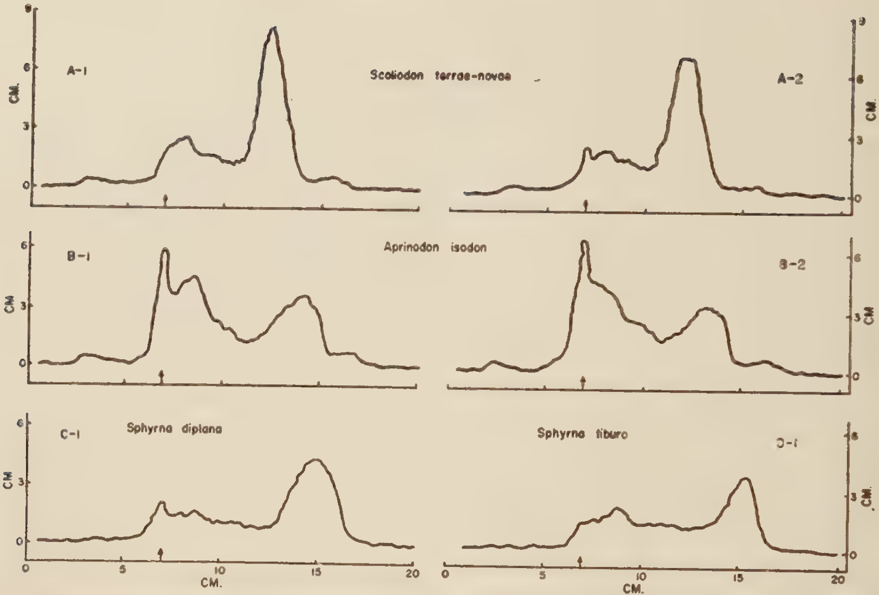

Fig. 2. Filter paper electrophoretic patterns of the same serum samples shown in Figure 1 but analyzed after one week storage in a deep freeze.

The Spinco Model R Analytrol and Duostat were used in these experiments. The general operating instructions recommended for the analysis of human sera with this equipment were followed. We used the recommended Spinco Buffer B-2 (2.76 gm. diethyl barbituric acid and 15.40 gm. sodium diethyl barbiturate per 1000 ml. distilled water) at pH 8.6 and ionic strength of 0.075. One liter of this buffer was placed into each of two electrophoresis cells with a capacity of eight paper strips each. The paper strips were saturated with buffer. After a 30 to 40 min. equilibrium period, 0.02 ml. of each undiluted sample was applied to separate paper strips with a striper which was filled with a micropipette. A constant current of 12 milliamperes (at 115 volts) was applied for 19 hr. at room temperature (24°C–26°C). The paper strips were then dried in an oven for 30 min. at 120°C. After immersing the dried strips in Spinco Dye B-1 (0.1 gm. bromphenol blue dissolved in 50 ml. of 95 percent ethyl alcohol plus 31 gm. zinc sulphate and made to 1000 ml. with 5 percent acetic acid) for 6 hr., the strips were rinsed twice in 1000 ml. of 5 per cent acetic acid for 6 min. periods. The paper strips were then fixed in Spinco Fixative B-2 (9.0 gm. sodium acetate dissolved in 1000 ml. of 10 per cent acetic acid) for 6 min. After blotting, the stained strips were dried in a preheated oven at 120°C for 15 min. and subsequently scanned with the analytrol.

RESULTS AND DISCUSSION

The serum protein patterns obtained from the dyed paper strips with the analytrol are shown in Figure 1. The majority of components migrated toward the anode (right of the arrow). The sera of *Scoliodon* and *Aprinodon* contain one component which moved toward the cathode (left of the arrow). This component is hardly noticeable in samples of the two *Sphyrna* species. Patterns are similar between different individuals of the same species (A-1 and A-2, B-1 and B-2). However, significant quantitative differences are evident between members of the three genera as shown by the presence or absence, relative concentrations, mobility, and direction of migration of the different components. Comparison of the patterns of the two *Sphyrna* species (C-1 and D-1) shows the lesser amount of variation between different species of the same genus.

The key in Fishes of the Western North Atlantic (Tee-van, 1948) places all four genera within the suborder *Galeoidea*; the genera *Scoliodon* and *Aprinodon* are in the family *Carcharhinidae*; and the genus *Sphyrna* is in the family *Sphyrnidae*.

he same serum samples were reanalyzed
2) after one week storage in a deep-freeze.
parison of Figures 1 and 2 shows the minor
rences that resulted and the reproducibility
e patterns by the techniques used.

e data presented in this preliminary report
ld be interpreted with caution. Moore
5) studied sera patterns of rats, cats,
k and pig embryos. He showed major
nges in serum patterns with age and de-
pment. He advanced the possibility that
from the same species living under different
litions might present a pattern different
the one considered typical. Dessauer and
(1956) studied the plasma patterns among
nbers of the order *Amphibia* and *Reptilia*.
y found differences in patterns due to sex,
starvation, season, and geographic varia-
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The Effect of Copper on the Growth of Bacteria Isolated from Marine Environments

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ABSTRACT

The use of copper may prove feasible for the control of catastrophic fish mortalities associated with blooms of *Gymnodinium brevis.* Prerequisite is knowledge of the effect that relatively high concentrations of copper may have on the marine community as a whole. In this study the effect of copper on the growth of 145 marine bacteria was measured. All of the bacteria grew in a medium containing copper in concentrations up to 0.25 mg/L. This concentration was compared to the *in vivo* (0.2 mg/L) and *in vitro* (0.1 mg/L) lethal dose of copper for *G. brevis.* In addition, the growth of approximately 4 per cent of the bacteria was stimulated by this concentration of copper.

INTRODUCTION

During the latter part of 1955, red tide outbreaks associated with *Gymnodinium brevis* were reported along the Gulf coast of Mexico and along the southeast coast of Texas (Wilson and Ray 1956). These blooms were accompanied by extensive kills involving millions of pounds of commercial and game fish, paralleling the destructiveness of Florida's 1946 outbreak (Gunter *et al.* 1948, Galtsoff 1948). In all of these instances *G. brevis* (Davis 1948) was identified and found in large numbers. Other red tide outbreaks have been reported (Feinstein *et al.* 1955, Lackey and Hynes 1955).

Recently *G. brevis* was isolated and is being maintained in pure culture. Results of laboratory experiments by Dr. S. Ray and Mr. W. Wilson[1] with unialgal and pure cultures demonstrated that concentrations of *G. brevis* comparable to those of the Florida red tide were toxic to fish.

This paper reports on one aspect of a major project concerning red tide control measures presently in progress by the Gulf Fishery Investigations of the U. S. Fish and Wildlife Service. The study was prompted by the proposal that treatment of possible foci of infection with heavy metals may prove practical for the control of catastrophic blooms of *G. brevis.* Prior to large-scale field operations, it was decided to investigate the possibility of adverse effects of heavy metals on organisms other than *G. brevis.* Copper was selected because initial studies by Mr. Wilson showed that *G. brevis* is extremely sensitive to concentrations of copper only slightly above those normally present in regions along the west Florida coast (Mr. J. Bell[1]).

Copper has been used extensively for the control of algal blooms. Whipple (1948) cited Kellerman who studied the effect of copper sulfate upon fresh-water fish. It was shown that concentrations used for the destruction of microscopic organisms were close to the doses that would kill fish. A list was compiled by Chow and Thompson (1952) of the copper content of sea water found by various investigators in a variety of localities. Riley (1937) found a range of 0.001–0.015 mg/L off the mouth of the Mississippi River. At one of his stations a range of 0.02–0.025 mg/L was found. Atkins (1953) reported a seasonal variation of copper in surface waters of the English Channel ranging from 0.0015 mg/L in early autumn to 0.025 mg/L in winter. Higher values for Long Island Sound (Prytherch 1934, Galtsoff 1943) were attributed by Chow and Thompson (1954) to discharges of industrial wastes.

The effect of copper on various organisms involved in marine fouling has been re-blooms, the concentration of copper could be effectively increased to 0.25 mg/L without bactericidal effects. Harvey (1955) estimated that the concentration of cupric ion which is toxic to marine plants and animals was approximately 1.0 mg/L. This concentration is approximately 10 times higher than the lethal dose for *G. brevis* in laboratory experiments and 5 times the minimum lethal dose (MLD) established by Mr. Bell in red tide areas along the west coast of Florida. At copper concentrations of 1.3 mg/L, approximately 1.4 per cent of the bacteria screened did not grow. Waksman *et al.* (1943) reported that concentrations of copper up to 10 mg/L did not affect the number of bacteria found in water taken near the dock of the Oceanographic Institution at Woods Hole. Thus, it appears that an *in vivo* MLD of 1.3 mg/L would not materially affect the growth of bacterial populations. In addition, this concentration of copper stimulated the growth of 4 per cent of the cultures as shown in Figure 2, Curve *C*.

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[1] We should like to thank Dr. S. Ray and Mr. W. Wilson of this laboratory and Mr. J. Bell of our field station in Naples, Florida, for making this information available prior to publication.

SUMMARY

Bacteria were isolated from a number of marine samples. On the basis of differential morphological and physiological properties, 145 different cultures were selected and the effect of increasing copper concentrations on their growth was measured.

Growth patterns of the cultures as affected by copper were divided into four representative groups which are described.

All of the cultures grew in a basal medium containing a copper concentration of 0.25 mg/L. Seventeen per cent tolerated up to 50.9 mg/L which was the highest concentration of copper tested. These values were compared with the *in vitro* lethal concentration (0.1 mg/L) for *Gymnodinium brevis* and the estimated minimum lethal dose (MLD) *in vivo* (0.2 mg/L). At the MLD level, all of the bacteria grew and the growth of approximately 4 per cent was stimulated.

Considering that the bacteria tested were representative of areas susceptible to *G. brevis* blooms, an *in vivo* MLD of 1.3 mg/L would not materially interfere with the growth of these bacteria and may be beneficial to some.

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STARR, JONES AND MARTINEZ

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The Production of Vitamin B_{12}-Active Substances by Marine Bacteria

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ABSTRACT

The production of members of the vitamin-B_{12} family of compounds by 34 marine bacteria that were grown in a B_{12}-deficient medium was assayed. Using aliquots of the same bacterial culture, 70 per cent and 30 per cent had activity for the assay organisms *Escherichia coli* 113-3 and *Euglena gracilis*, *z* strain, respectively. Using the *Euglena* assay, no apparent relation was evident between the activities of the cell residues or corresponding supernatants and the relative amount of growth of each culture. However, of the 24 bacterial cultures tested, the supernatants of 42 per cent had activity, whereas the corresponding cell residues of 63 per cent had activity.

INTRODUCTION

Extensive reviews are available on members of the vitamin-B_{12} family of compounds dealing with their chemistry, functions in animal and microbial metabolism, distribution, production, and methods of measurement (McNutt 1952, Jukes *et al.* 1954, Hoff-Jørgensen 1954, and Ford and Hutner 1955). Burton and Lochhead (1951) and Lochhead and Burton (1955) have demonstrated that vitamin B_{12} is required by certain soil bacteria. Vitamin B_{12}-active compounds have been shown to be essential or stimulatory for the growth of various marine microorganisms (Hutner and Provasoli 1953, Droop 1954, Lewin 1954, Sweeney 1954, Droop 1955, and Wilson and Collier 1955). Such observations suggest that vitamin B_{12}-active compounds may have a vital role in the economy of the oceans, in production of algal blooms, and in population successions.

In previous studies (Starr 1956), the vitamin-B_{12} content of the suspended matter of estuarine and oceanic waters was assayed. The present investigation was undertaken to learn more about the vitamin-B_{12} cycle in marine environments. Information gained from this and related studies encompassing the vitamin cycles and the roles of organic compounds of the oceans may add materially to our understanding of marine ecology and its application to marine fisheries.

In this investigation microbiological assay procedures were used to measure the production of vitamin B_{12}-active compounds by 34 different bacteria isolated from marine environments. Relative levels of production were compared using two different microbiological assay organisms having different spectra of activity for members of the vitamin-B_{12} family of compounds.

EXPERIMENTAL

The 34 bacteria screened for production of vitamin B_{12}-active substances represent different morphological and physiological groups that are maintained in our permanent stock culture collection. They have not as yet been identified. They were isolated from a variety of marine samples by techniques described in a previous publication (Starr and Jones 1957).

The bacteria were grown in a vitamin B_{12}-deficient medium of the following composition: NaCl, 0.3 g; $MgSO_4 \cdot 7H_2O$, 0.02 g; KNO_3, 0.02 g; NH_4Cl, 0.01 g; K_2HPO_4, 0.04 g; Na acetate, 0.01 g; sucrose, 0.1 g; glycine, 0.01 g; yeast extract 0.02 g; and distilled water to 100 ml. The pH was adjusted to 7.5–7.7 with 1N NaOH. After 10 days' incubation at 26°C ± 2°C, aliquots of each culture were diluted 1:10 with a buffer at pH 4.5. The buffer contained 8.2 g/L of KH_2PO_4 and 0.5 g/L of $Na_2S_2O_5$. The diluted cultures were hydrolyzed in a boiling water bath for 20 min. After cooling, a second 1:10 dilution was made from the first with the same buffer. These dilutions, 1:10 and 1:100, of each culture were diluted further with distilled water to give the following final assay dilutions: 1:10, 1:20, 1:50, 1:100, 1:200, 1:500, 1:1000.

The following procedures were used in order to determine if vitamin B_{12}-active substances were confined to the bacterial cells or released into the medium. Twenty-four of the 34 bacteria were grown in 400 ml of medium in 1000 ml Erlenmeyer flasks. The cultures were incubated at 26° ± 2°C on a rotary shaker for 6 to 8 days. Twenty-ml aliquots of each culture were centrifuged at 10,000 rpm for 10 min at 4°C. The supernatant was decanted, and final dilutions were prepared from it. The cell residues were suspended in 10 ml of the phosphate-metabisulfite buffer, and final dilutions were made. Other aliquots of each culture were used for turbidimetric growth measurements using a Klett-Summerson colorimeter and for pH measurements.

Samples were assayed for vitamin-B_{12} activity using *Euglena gracilis*, *z* strain, (Pringsheim's) which was obtained through the courtesy of Dr. L. Provasoli. It is now available from the American Type Culture Collection. The methods and procedures were essentially those of Hutner *et al.* (1956) with minor modifications. Stock cultures of *Euglena* were maintained in screw-cap tubes containing: K_2HPO_4, 2 mg; $Na_2 \cdot citrate \cdot 2H_2O$, 2 mg; $FeCl_3 \cdot 6H_2O$, 0.2 mg; peptone, 60 mg; trypticase, 16 mg; yeast extract, 5 mg; and made to volume with 100 ml of distilled water. The pH was adjusted to 6.5. Assays were performed in screw-cap tubes (size 125 x 20 mm) using the basal medium, "dry mix", described by Hutner *et al.* (1956). Two and one-half ml of the double-strength basal medium were added to 2.5 ml of each dilution of the sample. Duplicate standard curves were made using commercial vitamin B_{12} to give the following final concentrations (mμg/100 ml): 0.0, 0.05, 0.12, 0.2, 0.3, 0.4, 0.5, 0.6, 0.8, and 1.0. All media were autoclaved at 15 lb for 10 min prior to inoculation. A 6 to 8 day-old *Euglena* culture grown in the stock culture maintenance medium was used for inocula. A bacteriological loop was used to transfer approximately 0.05 ml to 12 ml of the basal medium. One drop of the resulting suspension (approximately 0.08 ml) was used as inoculum per assay tube. Although it has been shown (Østergaard Kristensen 1954) that the supernatant fluid of well-grown *Euglena* cultures contains material which inhibits the growth of *Euglena* in concentrations as low as 1 in 2000 (Hutner *et al.* 1956), our dilution represented a safe margin with a concentration of approximately 1:15,000. Cultures were incubated under a battery of fluorescent lights at 27° ± 1°C for 6 days. Growth was measured using a Klett-Summerson colorimeter.

The other assay organism was the mutant strain *Escherichia coli* 113-3 obtained through the courtesy of Dr. B. D. Davis. The methods of assay were essentially those described by Burkholder (1951) and modified as described previously (Starr 1956). Stock cultures of *E. coli* were maintained on nutrient agar slants and were transferred weekly. Assays were performed as described for *Euglena*. Standard curves were made in duplicate to give the following final concentrations of commercial vitamin B_{12} (mμg/100 ml): 0.0, 1.0, 2.0, 5.0, 10.0, 15.0, 20.0, 30.0, and 40.0. All media were autoclaved at 10 lb for 3 min prior to inoculation. Inocula were prepared from a 24-hr slant of *E. coli* by carefully transferring a small amount of growth with a fine platinum needle to 12 ml of single strength basal medium. One drop (approximately 0.08 ml) of this cell suspension was used per tube. Experiments were incubated for 18 to 20 hr at 30°C on a tissue-culture apparatus rotating 20 to 24 rpm. Growth was measured turbidimetrically with a Klett-Summerson colorimeter.

RESULTS

Typical assay response curves for *Euglena* and *E. coli* to increasing concentrations of commercial vitamin B_{12} are shown in Figure 1.

The results of the preliminary screen to determine the numbers of bacteria producing vitamin B_{12}-active substances are given in Table 1. Using aliquots of the same culture, 70 per cent and 30 per cent of the isolates

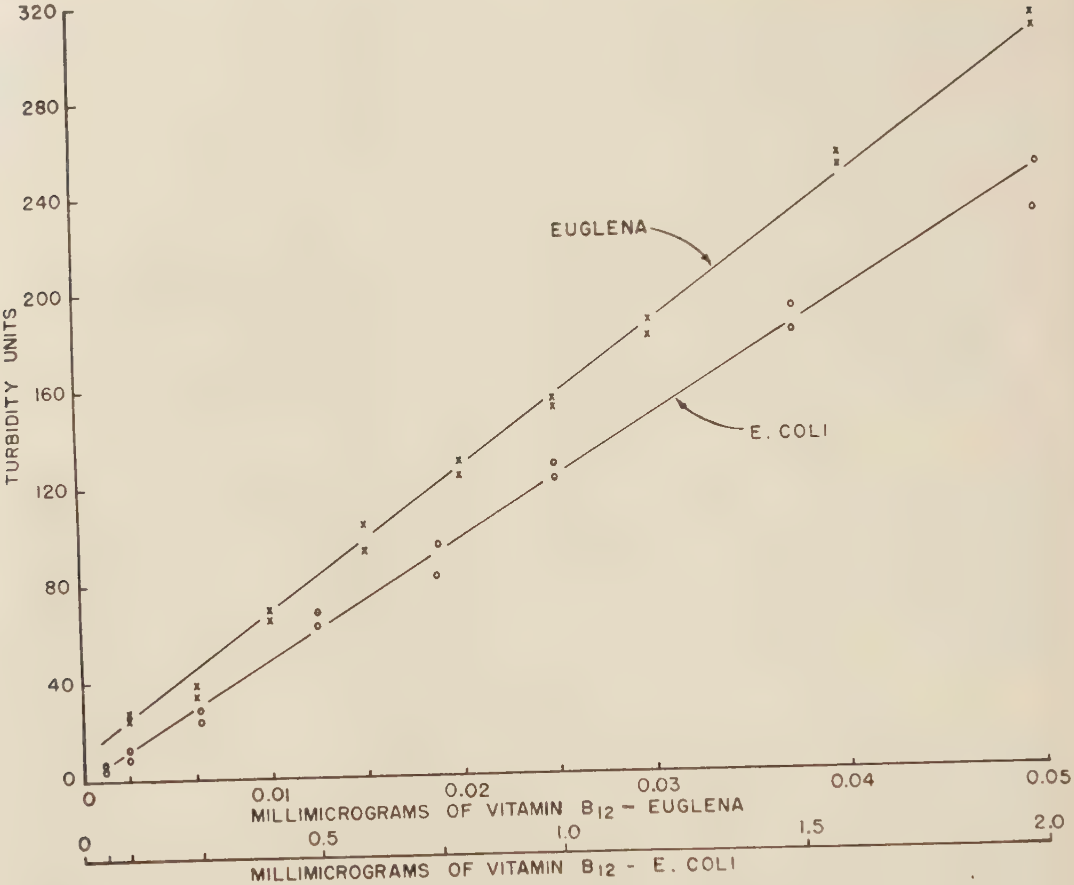

FIG. 1. Responses of *Euglena gracilis*, *z* strain, and *Escherichia coli* 113-3 to increasing concentrations of vitamin B_{12} per 5 ml of medium.

showed activity by the *E. coli* and *Euglena* assays, respectively. In no instance was a culture positive for *Euglena* and negative for *E. coli*.

The relative levels of vitamin B_{12}-activity produced by the different cultures ranged from 0 to 5.0 mμg/ml as measured by the *Euglena* assay and from 0 to 18.4 mμg/ml as measured by the *E. coli* assay.

Other experiments were designed to determine if vitamin-B_{12} activity was confined to the bacterial cells or released into the medium. The cell residues and supernatants of mass cultures were obtained and processed as described. Aliquots of them were assayed with *Euglena*. For comparison, the same cultures used in the previous experiments (Table 1) were screened.

Of the 24 cultures tested, the cell residues of 63 per cent showed activity, whereas the corresponding supernatants of only 42 per cent showed activity (Table 2).

There was no apparent relationship between the amount of growth (turbidity readings) or final pH of each culture and the levels of vitamin-B_{12} activity of either the cell residues or supernatants. For example, the vitamin-B_{12} activity of culture 266 which grew meagerly (turbidity, 15) was confined to the cell residue. Other cultures (126 and 222B) which grew prolifically produced relatively less activity. In no instance did a supernatant have activity and its corresponding cell residue have none, although the reverse situation occurred a number of times.

TABLE 1. *Comparative responses of* Escherichia coli *113-3 and* Euglena gracilis, z *strain, to aliquots of the same bacterial cultures*

Units of activity in terms of mμg vitamin B_{12} per ml.

Culture No.	*E. coli*	*Euglena*
Control	0	0
112	1.2	0.50
116	3.4	1.36
117	3.8	1.38
121	13.0	4.20
122	0	0
126	1.2	0
127A	0	0
127B	0	0
143	1.1	0
144	0.70	0
148	0	0
149	0.98	0
202	1.4	0
203	0	0
205	2.8	1.36
209	0.75	0.24
215	0.70	0
222A	0	0
222B	1.3	0
233	5.0	1.90
238	1.0	0
245	16.7	4.30
249	1.3	0
250	0	0
255	0	0
259	1.1	0
260	0.40	0
266	1.4	0
276	1.4	0.60
279	0.95	0
286	0	0
287	0	0
288	3.4	0.36
306	18.4	5.00

TABLE 2. *Response of* Euglena gracilis, z *strain, to preparations of the supernatants and cell residues of bacterial cultures, and accompanying data on pH and Klett units of growth*

Units of assay activity in terms of mμg vitamin B_{12} per ml.

Culture No.	Klett units	Final pH	Cell residues	Supernatants
Control	0	7.4	0	0
112	107	7.0	7.00	0.048
116	64	8.4	4.50	0.200
117	66	8.2	2.68	0.035
121	35	7.4	16.2	0.550
122	48	8.4	0	0
126	295	6.3	0.16	0
127A	45	8.2	0.02	0
127B	45	8.2	0	0
143	289	6.4	0	0
144	54	6.9	0	0
148	40	5.9	0	0
203	20	8.2	0	0
205	168	6.6	13.3	0.059
209	110	7.3	1.50	0.004
222A	29	8.3	0	0
222B	222	5.8	0.05	0
233	65	6.8	1.88	0.038
238	107	8.0	0	0
249	259	6.7	0.10	0
250	29	8.5	0	0
266	15	7.7	11.9	0
276	215	7.7	14.0	0.055
279	182	5.0	0.21	0.022
306	30	7.5	3.84	0.870

DISCUSSION

The responses of *E. coli* and *Euglena* to members of the naturally occurring B_{12}-vitamins are discussed in detail by Coates and Ford (1955), Ford and Hutner (1955), and Hutner *et al.* (1956). *E. coli* responds to non-specific substances such as methionine and to Factor B, whereas *Euglena* does not respond to either of them. Factor B (Kon 1955) is the non-nucleotide moiety common to several of the B_{12}-vitamins. If this factor or any one of a number of nucleotides are present, some organisms can complete the synthesis of a form of "vitamin B_{12}" containing that particular nucleotide (Coates and Ford 1955). From the standpoint of the requirements of man, the clinically active vitamin B_{12} or cyanocobalamin is of particular importance. From the standpoint of the growth requirements of marine microorganisms, the pseudovitamin B_{12} and related factors may prove to be as important as cyanocobalamin. Various investigators have demonstrated that cyanocobalamin is a growth factor required by some diatoms and flagellates (Provasoli and Pintner 1953). In addition, Droop (1955) showed that the cyanocobalamin required by the pelagic diatom *Skeletonema costatum* was spared by pseudovitamin B_{12}, Factor A, and Factor B. His noteworthy observations on the lack of specificity of the form of vitamin B_{12} preferred by this diatom indicates the probable importance of "cobalamins" (members of the vitamin-B_{12} family of compounds in addition to cyanocobalamin) in the economy of the sea.

In this investigation vitamin B_{12}-activity produced by marine bacteria was measured with *Euglena* and *E. coli* both of which have different spectra of activity. Of the 34 cultures screened, 30 per cent and 70 per cent had activity for *Euglena* and *E. coli*, respectively. These data are in agreement with those of Ericson and Lewis (1953) who screened 34 cultures using the *E. coli* 113-3 cup-plate assay and found that 70 per cent were producers. Burton and Lochhead (1951) found that 65 per cent of their bacterial cultures were producers. They examined terrestrial isolates using the *Lactobacillus lactis* assay. A table describing the responses of the different assay organisms to vitamin B_{12}-active compounds is given in Ford and Hutner (1955).

In all cases involving aliquots of the same culture which were tested with both assay organisms, the *E. coli* assay gave decidedly higher values (Table 1). This observation indicates the broader spectrum of response of *E. coli* to vitamin B_{12}-active substances compared to *Euglena* and the wide variation of specific vitamin-B_{12} activity produced by different cultures under similar conditions. The maximum levels of vitamin-B_{12} activity produced by culture no. 306 were 5.00 and 18.4 mμg/ml for *Euglena* and *E. coli*, respectively. Using the *L. lactis* assay Burton and Lochhead (1951) found terrestrial bacteria which produced over 500 mμg activity per ml of culture medium. Burkholder and Burkholder (1956) found marine bacteria which produced up to 150 mμg/ml. They used the *E. coli* agar plate method. Using the *E. coli* 113-3 cup-plate assay, Ericson and Lewis (1953) found marine bacteria which produced 0.005–140 mμg/ml. They stated that a level of approximately 10 mμg/ml is more comparable to those obtained for bacteria isolated from seawater and seaweed. This figure is in agreement with the levels (0.40–18.4 mμg/ml by *E. coli*) found during this investigation.

In experiments designed to determine if vitamin B_{12}-activity was confined to the cell residues or released into the medium, results varied with each culture as shown in Table 2. In general intracellular levels of vitamin B_{12} were higher than extracellular. No apparent relationship was evident between the levels of activity of either the cell residues or supernatants and the final bacterial growth or pH of the medium.

As shown in this and related studies by other investigators, the amount and specificity of B_{12}-activity produced by a particular bacterial culture varied with the conditions of the experiment and methods of measurement.

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The Vitamin-B_{12} Activity of Mullet and Shark Serum

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ABSTRACT

Microbiological assay procedures using *Euglena gracilis*, *z* strain, were employed to measure the vitamin-B_{12} activity of samples of mullet, shark, and human sera. The average activity was 10.7, 0.84, and 1.15 mμg/ml, respectively. The relatively higher activity of mullet sera compared to shark sera may reflect significant physiological differences between these subclasses of fish and possibly different feeding habits.

Bacteria isolated from mullet intestinal contents were grown in a vitamin B_{12}-deficient medium. Of 8 cultures tested, 6 had vitamin-B_{12} activity when assayed with *Escherichia coli* 113-3 and 1 had activity for *Euglena*. In other experiments concentrates of cell residues were assayed. Two out of 4 supposedly negative vitamin-B_{12} producers had activity for *Euglena*.

INTRODUCTION

The economy of the oceans is influenced to a great extent by the diverse physiological activities of its microscopic communities. Many of these microscopic populations are dependent upon the availability of specific nutrilites or essential growth factors for growth and development. Of those marine microorganisms that have been studied in the laboratory, several diatoms (Hutner and Provasoli 1953, and Droop 1955) and algal flagellates (see list compiled in Provasoli and Pintner 1953) have a requirement for some member of the vitamin-B_{12} family of compounds.

Vitamin B_{12}-active substances are added to the environment as a result of the metabolic activities of various marine microorganisms. Ericson and Lewis (1953) found that 70 per cent of 34 bacterial cultures isolated from marine sources produced vitamin B_{12}-active compounds. Similar data were obtained by Starr *et al.* (1957), although different assay procedures were used. Water movement and other physical factors undoubtedly aid in the dissemination of these products of microbial origin. Thus, these products may influence distant as well as neighboring populations. The suspended matter of sea water with its inherent and/or adhering nutrients contained appreciable quantities of vitamin B_{12} (Starr 1956, and Burkholder and Burkholder 1956). Ericson and Lewis (1953), who assayed the vitamin-B_{12} activity of seaweed, attributed activity to synthesis by bacteria living epiphytically on the algae rather than to the synthesis by the alga itself.

Several investigatiors have reported the presence of vitamin B_{12}-active substances in marine vertebrates and invertebrates. Masaaki (1952) measured and compared the vitamin-B_{12} activity of the organs of fish. He reported also on the presence of vitamin B_{12} in univalves and bivalves (Masaaki 1953). Maxwell (1952) found that molluscs are, in general, richer in vitamin B_{12} than echinoderms, crustaceans, or annelids. Oysters, clams, and to a lesser extent shrimp had appreciable vitamin-B_{12} activity (Robbins *et al.* 1951) suggesting that algal flagellates, an important item in their diet, are either producers or accumulators of vitamin B_{12}-active substances (Provasoli and Pintner 1953).

In this investigation the vitamin-B_{12} activity of mullet and shark sera were measured using microbiological assay procedures. An attempt was made to account for the higher vitamin-B_{12} activity of mullet serum by examining the intestinal bacteria of mullet for their ability to produce vitamin B_{12}-active compounds.

METHODS

The blood samples of 10 mullet and 6 sharks (Table 1) were obtained by cardiac puncture with a glass capillary pipet. In order to avoid contamination by body fluids, only one puncture was made per fish. Approximately 2 to 5 ml of blood from each fish was transferred into test tubes and allowed to clot undisturbed at room temperature (25°C ± 2.0°C) for several hours. The extruded sera were centrifuged at 8,000 rpm for 5 min at 4°C. Samples were either assayed immediately or stored at −5°C for 8 days prior to use.

For comparative purposes 7 serum samples from man were assayed.

Bacteria were isolated from the intestinal contents of mullet using routine bacteriological techniques. The composition of the medium used for isolation and maintenance of stock cultures has been described previously (Starr and Jones 1957).

The serum samples and bacterial isolates were assayed for vitamin-B_{12} activity using *Euglena gracilis*, *z* strain, and *Escherichia coli* 113–3. Cultures of these assay microorganisms were obtained through the courtesy of Dr. L. Provasoli and Dr. B. D. Davis, respectively. Except for the dilutions of the serum samples which were made with distilled water, the assays were conducted as described earlier (Starr *et al.* 1957).

RESULTS

The relative vitamin-B_{12} activities of mullet, shark, and human sera are listed in Table 1. The activity of mullet sera ranged from 4.6 to 18.4 mμg/ml (av. 10.7), shark sera ranged from 0 to 2.8 mμg/ml (av. 0.84), and human sera ranged from 0.54 to 2.06 mμg/ml (av. 1.15).

TABLE 1. *Relative vitamin-B_{12} activity (mμg/ml) of sera samples as assayed with* Euglena gracilis, *z strain*

Specimen number	Mullet*	Human	Shark	
1	4.6	0.54	2.81	*Aprionodon isodon*
2	13.4	1.07	1.39	" "
3	13.5	0.73	0	*Scoliodon terrae-novae*
4	6.6	1.20	0.20	" "
5	17.0	2.06	0	*Sphyrna diplana*
6	7.6	1.12	0.63	" *tiburo*
7	18.4	1.32		
8	7.8			
9	7.3			
10	10.7			

* All mullet were *Mugil cephalus*.

TABLE 2. *Vitamin B_{12}-production in mμg/ml by bacterial cultures isolated from mullet intestinal contents as assayed with* Escherichia coli *113-3 and* Euglena gracilis, z *strain*

Culture No.	Aliquots of the same culture assayed by	
	E. coli	*Euglena*
233	5.0	1.9
238	1.0	0 (0)*
249	1.3	0 (0.10)
250	0	0 (0)
255	0	0
259	1.1	0
260	0.4	0
266	1.4	0 (11.9)

* The cell residues of mass cultures numbered 238, 249, 250, and 266 were concentrated by centrifugation and assayed. Their corresponding supernatants had no activity for *Euglena*.

Eight bacterial isolates obtained from mullet intestinal contents were grown in a vitamin B_{12}-deficient medium (Starr *et al.* 1957). Aliquots of the same culture were tested with *E. coli* and *Euglena*. Results showed that 6 cultures had activity for *E. coli* and 1 culture had activity for *Euglena*. However, in experiments designed to determine if vitamin B_{12}-active substances were released into the medium or confined to the bacterial cells, we found that concentrates of the cells of 2 out of 4 supposedly negative vitamin-B_{12} producers had positive activity for *Euglena* (Table 2).

DISCUSSION

The specificity of the available microbiological assay organisms for vitamin B_{12}-active substances is discussed in Ford and Hutner (1955). Briefly, *Euglena* is less specific than *Ochromonas* as it responds to pseudovitamin B_{12} and to factors A, C_1, and C_2, but it is more specific than *E. coli* and *Lactobacillus* (Coates and Ford 1955).

The assay techniques incorporating the *Euglena z* strain were developed by Hutner *et al.* (1956). Their procedures eliminated the excessive alkalinization that caused precipitation of serum proteins during growth of *Euglena*. These investigators stated that the mean normal concentration of human sera is about 0.360 mμg/ml. Mollin and Baker (1955) stated that the serum B_{12} concentrations of normal subjects ranged from 0.100 to 0.900 mμg/ml. Except for one serum which had an activity of 2.06 mμg/ml, we found a range of 0.54 to 1.32 mμg/ml which is in general agreement with the above values.

The activity of serum samples from mullet and shark ranged from 4.6 to 18.4 mμg/ml and 0 to 2.81 mμg/ml, respectively. The higher values for mullet serum compared to shark serum may reflect significant physiological differences between these subclasses of fish and possibly different feeding habits. Although the information in Table 1 is not conclusive, it suggests that the vitamin-B_{12} activity of shark serum differs between genera and species.

Why or how the mullet accumulates such significantly high and variable quantities of vitamin B_{12} in its serum is unknown. This vitamin does play an important role in the metabolism of animals (Arnstein 1955) and microorganisms (Lascelles and Cross 1955). Although the bacterial flora of mullet intestinal contents may not represent a resident population, the relative percentage of vitamin-B_{12} producers in mullet intestine is about the same as that found in marine muds and waters (Starr *et al.* 1957) and in association with seaweeds (Ericson and Lewis 1953). Mullet may obtain vitamin B_{12} either directly from their food or from their intestinal flora or from both sources.

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A STUDY OF THE INVERTEBRATE BOTTOM FAUNA OF GREENWICH BAY, RHODE ISLAND

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A STUDY OF THE INVERTEBRATE BOTTOM FAUNA OF GREENWICH BAY, RHODE ISLAND

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Introduction

The Clam Investigations of the U. S. Fish and Wildlife Service were established by Congress in 1948 under legislation sponsored by the Atlantic States Marine Fisheries Commission to conduct biological investigations of the soft clam (*Mya arenaria*) and the hard clam (*Venus mercenaria*). The hard clam or quahog section of this Investigation is centered in Rhode Island. An important part of this research is a field study of a population of quahogs in a limited area to determine how many bushels can be removed each year by the commercial fishery. Greenwich Bay, an arm of Narragansett Bay, was chosen for these productivity studies. Quantitative sampling surveys, an essential part of the field studies, were made in the bay during the summers of 1950, 1951 and 1952.

In the summers of 1951 and 1952 a general ecological study was made of the entire invertebrate bottom fauna with particular reference to certain aspects of the quahog problem. The principal aims of this ecological study were:

1) to describe the bottom invertebrate population,
2) to find out whether any organisms were particularly associated with *Venus* within the bay,
3) to determine whether localities which had always been poor in clam production were also barren of other forms of life as well, and
4) to find out which species were characteristic of a good clam-producing area with the idea that this information might be useful in appraising other potential clam-producing areas.

The Study Area

The shape, extent and other geographic features of Greenwich Bay are shown in Figure 1. The depth is almost uniform at 10 to 14 feet with the exception of a narrow channel near the mouth which is from 20 to 30 feet in depth and is probably a relic of a submerged river system. There appears to be little relationship between it and the water currents or the distribution of recent sediments. North and south of this channel, shallow sandy shelves extend several hundred feet from the shore line.

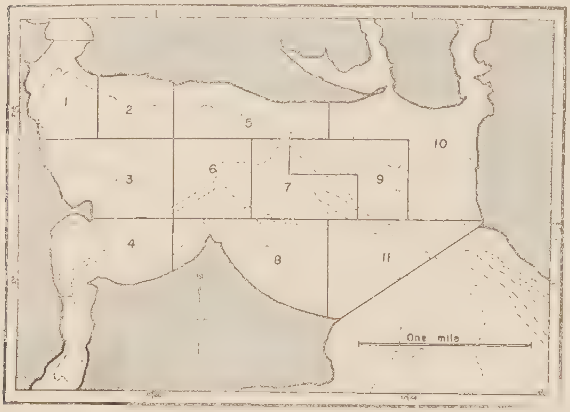

FIG. 1. Greenwich Bay: depth contours in fathoms and ecological sectors referred to in the text.

The distributions of the various types of bottom sediments are shown in Fig. 2. A simplified sediment analysis for the numbered locations is given in Table I. As can be seen, four principal sediment types are present. These include a black, silty mud, rich in organic detritus and sulphides; sand; mixtures, in various proportions, of silt and sand; and mixtures of silt, sand and broken shell.

The intertidal and immediate subtidal bottoms are sand, with occasional patches of rocks and gravel.

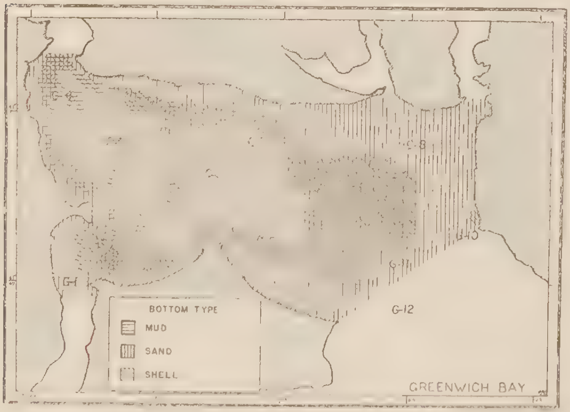

FIG. 2. Bottom Types. Where the symbols overlap the general bottom types are in combination. Numbers indicate locations of the geological samples referred to in Table I.

The central core of the bay is mud composed principally of silt-sized particles with some clay and sand. The sand bottom occurs near the mouth of the bay where the water is somewhat shallower and exposed to the prevailing southerly winds in summer and easterly storms in winter.

TABLE I. Median diameter of sediment particles, sorting coefficient, organic content and pH of sediments from twelve geological stations; total number of species in five samples taken in each locality

Geological stations	Bottom type	Median diameter (microns)	Sorting coefficient	Percent organic*	pH	Number species in 5 samples
1........	silt	22	2.23	...	...	8
2........	sandy-silt	50	3.15	5.0	...	19
3........	silt	8	2.18	6.6	...	11
4........	silt	20	1.61	5.6	7.2	18
5........	silt	8	1.06	4.2	7.3	15
6........	sandy-silt	54	2.44	3.9	7.4	19
7........	silt	18	2.27	4.9	7.6	22
8........	sand	240	1.29	0.7	7.4	27
9........	silty-sand and shell	260	3.33	2.3	7.5	20
10........	sand	80	1.91	3.0	. .	21
11........	sand	240	1.29	1.2	7.5	43
12........	sand	350	1.35	0.8	7.6	34

*Actually the percent loss of weight upon purging with H_2O_2

Because the bay is shallow, turbulence from wave action dissipates stratification of temperature and salinity, resulting in very uniform water conditions. Some vertical and horizontal gradients can be observed, however, particularly in the spring and after heavy rains or melting snow. These gradients are very slight or absent during the summer. During the period of the survey, water temperatures reached 26°C during the warmest part of summer, and exceeded 20° from early June through September. Salinity varied between 27 ‰ and 30 ‰.

The tidal currents are relatively slow. The water oscillates in and out, with a lobe of Narragansett Bay water pushing in toward the northwest with the rising tide. The greatest tidal excursion takes place across the broad shelf between the southwestern point of the entrance and the channel. Surface currents measured by the U. S. Coast and Geodetic Survey (Height 1938) in the mouth of Greenwich Bay did not exceed one-third of a knot during the whole tidal cycle. The mean velocity was 0.13 knots. As a strong south and southwest wind blows steadily during most of the summer, and as the bay is exposed to easterly storms, wind-caused currents are probably more active than tides as agents of sediment transport and equally important in plankton movements.

Pollution is an important environmental factor where it exists, and while the bay as a whole is free of pollution, both coves in the western end of the bay (Fig. 1) are polluted and closed to shellfishing. These receive sewage and industrial wastes from the towns adjacent to them. The high organic content of the bottom mud in much of the bay may be in part due to the influx of pollutants. Because it results in the legal closing of an area to shellfishing, pollution can result indirectly in the presence of large numbers of shellfish nd other fauna. Two very densely populated enthonic communities lie at the entrances of the olluted inlets.

SAMPLING METHODS

For the present investigation a "clamshell" type onstruction bucket (Fig. 3), operated by a winch nd hoisting tackle from a 40-foot vessel, was selected as a satisfactory sampling device. The lamshell bucket has several advantages over a egular commercial shellfishing dredge: 1. the size f the sample is more closely controlled; 2. an intact section of bottom is removed with all included rganisms; and 3. the natural appearance and the osition of organisms in the bottom can be observed.

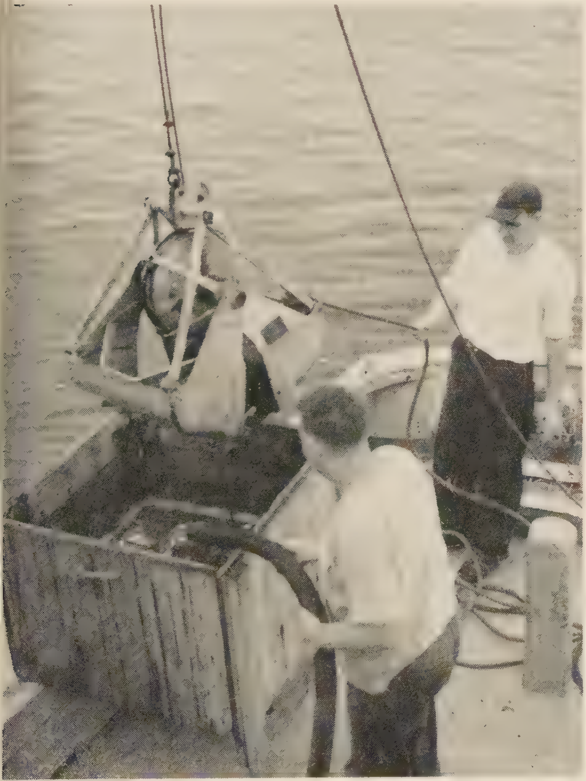

FIG. 3. The sampling gear used.

To collect a sample, the bucket was set down on the bottom with a force sufficient to sink the jaws and allow one level bucketful of bottom material to be scooped up. Since the force could be controlled by the speed of descent and distance of the free drop, a uniform sample size was possible in most cases, regardless of the softness of the bottom. The size of the sample was very close to one-half square meter to a maximum depth of about 30 centimeters.

The number of stations to be sampled was determined largely by the personnel and time avail- laid out on a chart, starting at arbitrary lines of latitude and longitude. This grid was transcribed on the water by fixing a starting position with sextant bearings or on some known navigational aid and laying buoys on either running time or by measurement while traveling a fixed compass course. Positions along this line were checked at several places with sextant fixes. All parts of the bay were thus covered except where soundings at high tide were too shallow to permit access by the vessel.

In 1952, on advice from a statistician, the sampling pattern was changed to concentrate more on the areas of high abundance of the hard clam. The bay was divided east and west into three areas. Two, the eastern and western, were of relatively high abundance and one, the middle, of low abundance. The grid was enlarged to stations 900 feet apart. In the two high-density areas the grid was laid down three times in each area and in the low density area it was laid down twice. The origin of the grid was picked from a series of random numbers. This resulted in sampling stations which were distributed at random within each area, except that each station was 900 feet from its neighbor in the same grid. Laying out the stations on the water and the actual sampling were accomplished in the same way as in previous years.

As each sample was brought on deck, a subsample of .05 square meters to a depth of 8.0 centimeters was taken from the surface. The bucket was then dumped into a large box fitted at the bottom with a screen of 12-mm mesh. The subsample was seived through a 2-mm mesh screen and the retained material preserved *in toto*. All specimens collected in the large screen were counted or preserved separately.

The subsampling of the surface was necessary in order to obtain those organisms small enough to pass through the 12-mm mesh. After several tests, it was found to be impractical to wash the whole sample through graded sieves. The smaller meshes were completely clogged in most cases by the mud tubes of the amphipod *Ampelisca*. Since the subsamples were taken from intact sediment, they can be considered to be practically equivalent to samples taken directly from the bottom and subject to the same statistical limitations. For a statistically valid sample, the organisms should be living within eight centimeters of the surface of the substrate and should be sufficiently numerous.

In both large samples and subsamples there are cases where in the sampling method may lead to inaccuracies, namely; 1. when organisms are of such sizes and shapes that some will be retained

2. when a species is collected in only scattered samples or is represented by only one individual in but occasional samples; 3. when the organisms burrow too deeply to be taken in the sampler. Since many of the worms, some bivalves, *Squilla, Upogebia* and many of the less common invertebrates fit into one or more of the above categories, it is obvious that their abundance can be indicated only in the most general terms. A limited number of other species can be treated more precisely in reference to their abundance. These are enumerated in Appendix Tables 2 and 3.

Besides the grid of regular stations, further samples were taken in particular localities selected on the basis of certain bottom types and depths. The data obtained from this supplemental survey were used to obtain a more accurate idea of the population in a number of type areas and to determine the variation between closely spaced samples.

A number of intertidal samples were also taken at intervals along the periphery of the bay.

Animal Communities

A complete list of the species collected during the summers of 1951 and 1952 is given in Appendix Table 1. Scientific names are in accordance with Miner (1950) and Pratt (1948), with the exception of the polychaetes which were identified by Dr. Marian Pettibone of the University of New Hampshire. Distribution of a few species is shown by contour lines on charts, but for reasons of space economy another method has been adopted for the presentation of this information for most of the species. The bay has been divided into eleven sectors, roughly according to the type of bottom sediment. Fig. 1 shows an outline chart with the boundaries of these areas superscribed. The numerical data in Appendix Tables 2 and 3 are given for each sector.

In the following discussion the term "community" is used in reference to the populations of several species living together in any particular area. The area may be defined either by the kinds of animals which make it up or by its physical nature. "Association" refers to situations where some interaction between species is apparent, or where there appears to be a positive correlation between the distributions of two or more species.

In Greenwich Bay the most important single factor in the organization of the bottom communities is the nature of the substrate. The various bottom types have already been discussed and each of these supports a characteristic community. The depth of water, proximity of the shore and the exposure to prevailing winds and storms also produce variations in the sort of organisms present in the different parts of the bay. Because of their complexity, it is diffcult to describe these communities adequately. One group of animals may occupy a deep stratum in the sediment while others live on or just below the surface of it. Some are perennial members of a community while others appear first in one and the following year in another. There are temporary populations of numerous juvenile individuals appearing now here, now there, which soon diminish to insignificance. There are ubiquitous species of general distribution and others occupying limited areas in a larger community, and many populations, large and small, overlap in complex fashion. The community concept has been systematically treated by such authors as Petersen (1913), Molander (1930), Shelford *et al.* (1935), and Dexter (1947). However, it is not intended here to become involved with specialized and often confusing terminology. The purpose is rather to describe as simply and graphically as possible the bottom populations and to account in some measure for their being distributed as they are.

Ampelisca Community

The most extensive community in Greenwich Bay occupies the muddy central core. Its dominant organism is an amphipod, *Ampelisca spinipes,* whose ribbon-like tubes of mud and mucoid substance form dense carpets over the surface of the bottom. In some places the density of these creatures exceeds 10,000 per square meter. Beneath the tubes of living individuals are layers several centimeters thick of the black and disintegrating tubes of past generations. Fig. 4 shows by contour the distribution of *Ampelisca* in 1952. In the previous year the distribution was about the same, but there was a greater abundance in the far western end of the bay. Living among the *Ampelisca,*

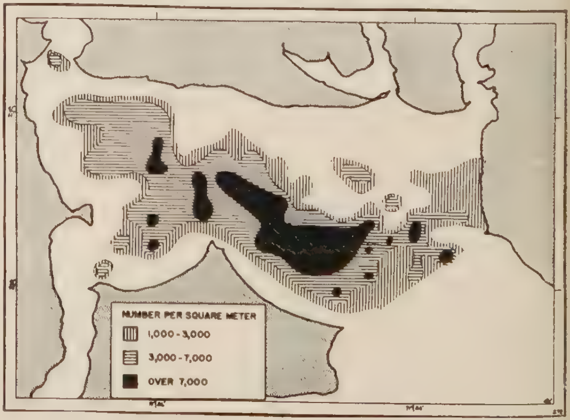

Fig. 4. The distribution of *Ampelisca spinipes* in 1952.

ut much inferior in numbers, is another amphipod, *Corophium cylindricum.* Also among the *Ampelisca* tubes dwell several other species in moderate numbers throughout the whole area. These include a tiny cirratulid worm, *Tharyx acutus;* a tectibranch snail, *Tornatina canaliculata;* and a small bivalve, *Macoma tenta. Podarke obscura* in a small polychaete worm which is a perennial inhabitant of the *Ampelisca* community but persists in a limited portion of it, roughly included by sectors 2, 3 and 6. An example of an adventitious member of the community is *Spiochaetopterus oculatus,* a tubicolous polychaete of which a sizable population appeared in 1952 occupying the south-central part of the bay (sectors 6, 7 and 8). During the previous year large numbers of this species occurred only in the sandy eastern part. Where *Spiochaetopterus* occurs abundantly, its upright annulated, parchment-like tubes, projecting slightly above the surface of the bottom, form a conspicuous feature. The abandoned tubes are often occupied by other species.

Certain bivalve molluscs, while not as numerous as some of the previous species, are characteristic of the *Ampelisca* community. *Nucula proxima, Macoma tenta* and *Pitar morrhuana* are the most common of these. In times past, as evidenced by quantities of shells buried in the mud, *Mulinia lateralis* was another. At the present time, however, adults of this species are not abundant anywhere in the bay. *Venus mercenaria* is present also, but, like many other species living in the *Ampelisca*-dominated community, it is present almost everywhere and is less numerous in the mud than elsewhere. In a deeper stratum live the burrowing crustaceans *Squilla empusa* and *Upogebia affinis.* Creeping over the surface are occasional foraging *Nassa obsoleta* and the drilling snails *Eupleura caudata.*

In general the *Ampelisca* community can be characterized as having enormous numbers of a single dominant species but comparatively few other species, and these are represented as either local populations of numerous individuals or diffuse populations of few individuals per unit area.

Crepidula-Nereis-Neopanope Association

The best-defined animal community is one which occupies the area circumscribed by sector 9 and a few other scattered similar localities (Fig. 5). It is one of the best examples of an animal association to be found in Greenwich Bay. The dominant organism is *Crepidula fornicata.* Clusters of this snail, with younger individuals stacked up on the older ones underneath, lie everywhere partly buried in the sediment, more than 20% of which is composed of shells and shell fragments of several species of molluscs. Toward the western end of the region many specimens of *Anomia simplex* are present with the *Crepidula.*

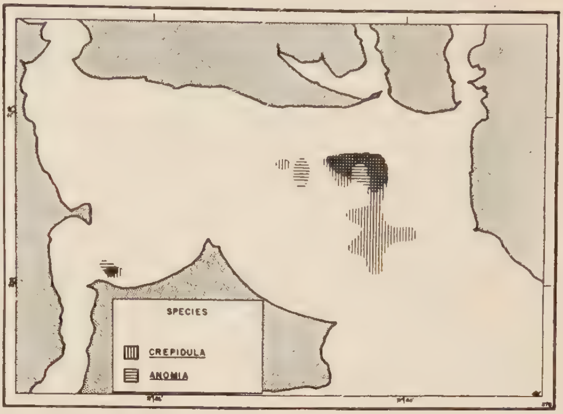

FIG. 5. The distribution of *Crepidula fornicata* and *Anomia simplex* in 1951.

Both of these species require a hard surface on which to attach, and the old parental shells of both provide ideal substrates for subsequent generations. In this way a colony maintains itself year after year.

The masses of shell also provide excellent shelter for numerous creeping and burrowing invertebrates. One of these is the polychaete *Nereis succinea,* which occurs in far greater numbers here than anywhere else in the bay (Fig. 6), and also attains greater size. Only one individual out of 274 collected in the entire remainder of the bay was longer than 40 millimeters. On the other hand, 23 out of 238 collected in sector 9 alone exceeded that length.

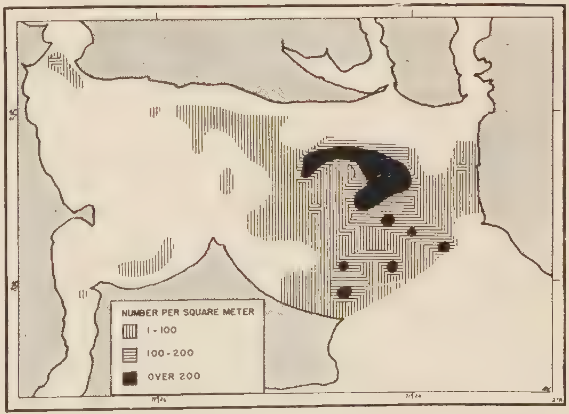

FIG. 6. The distribution of *Nereis succinea* in 1952.

Creeping about the bottom in considerable numbers are two species of crabs: *Neopanope texana,* the mud crab, and *Libinia emarginata,* the spider crab. As many as 20 of the former were taken on several occasions in the sampling bucket at one time.

The oyster drill, *Urosalpinx cinerea,* another member of this community, finds excellent feeding on the abundance of exposed molluscs (*Crepidula* and *Anomia*), and the shells of the latter provide suitable surfaces on which the drills may deposit their egg capsules.

Venus mercenaria is more abundant in the sand-silt-shell type sediment characteristic of the area occupied by this community than in any other type. The mean number per sample of *Venus* over 20 millimeters in size taken in various types of sediment were (in 1951) as follows: mud—2; silty sand—6; silty sand plus shell—12; pure sand—2. Fig. 7 shows the concentration of *Venus* in the *Crepidula-Anomia* community.

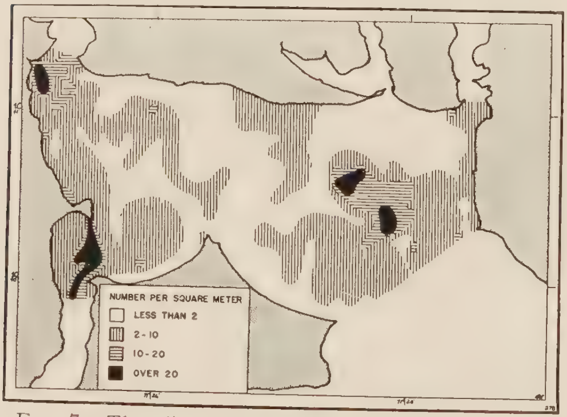

FIG. 7. The distribution of *Venus mercenaria* over 15 mm. in length in 1952.

On the wealth of exposed hard surfaces there are also a number of encrusting and attaching invertebrates. Among those collected were the bryozoans *Bowerbankia, Amathia, Membranipora, Schizoporella* and *Lepralia;* the tubicolous worms *Sabella* and *Hydroides;* and the boring sponge *Clione.* A similar but smaller *Crepidula-Anomia* community lies just above the point of land near the southeast corner of sector 4.

Sand bottom community

The remainder of Greenwich Bay has a bottom that is largely sandy. This sand ranges from clean, well-sorted material to various mixtures of sand and silt with some organic detritus. The population which occupies this extensive and rather variable area is less discrete as a community than the populations composing the other communities. It appears to be made up of extensions of some of the intertidal populations and elements of a larger community which extends beyond the limits of the study area into Narragansett Bay proper.

The most characteristic members of this san community, found throughout its extent in substantial numbers, are the razor clam *Ensis directu* and the bloodworm *Glycera dibranchiata* withi the sediment and the sand shrimp *Crago septemspinosus* and *Pagurus longicarpus,* the little hermi crab, creeping over the surface. Less numerou but very characteristic are the tube-dwelling wor *Diopatra cupraea* and the burrowing polychaet *Haploscoloplos fragilis.* A small bivalve, *Tellin tenera,* is common also.

Other species are abundant on occasion but no perennially; for instance, *Spiochaetopterus oculatus* formed a sizeable population in sector 10 in 1951 but was much less abundant here or anywhere in the sand region the following year. Numerous juvenile individuals of several species o bivalve molluscs (*Venus mercenaria, Ensis directus, Mya arenaria, Mulinia lateralis* and *Petricola pholadiformis*) settled in portions of the area in 1952 forming substantial temporary populations. At the time of the survey, predation by the drilling snail *Eupleura caudata* was already making inroads in their numbers. The high counts shown for these species in sectors 9, 10, and 11 in Appendix Table 3 are due to the numbers of juveniles.

Spio setosa and *Streblospio benedicti* are small polychaetes which form dense colonies in patches throughout the area, particularly in sectors 10 and 11, respectively. Another species of *Ampelisca, A. macrocephala,* was taken in many of the samples collected in sandy sediment.

Of particular interest among the animals of the sand bottom community is an archiannelid worm, apparently a new species of the genus *Polygordius.* The species differs from other species of the genus in the lack of a caudal enlargement. Unlike the genus *Chaetogordius,* which also lacks this enlargement, the Greenwich Bay species possesses no caudal bristles. It ranges in size from 20 to 30 millimeters. Most of the specimens were collected in sector 10.

In sectors 8 and 11 there is a transitional zone of considerable extent between the mud and sand bottoms (see Fig. 2). This zone contains populations of three kinds: members of the mud bottom community, members of the sand bottom community, and species found occasionally in either of these, but which are far more abundant in the transition zone. Two examples of such species are *Pectinaria gouldii,* a tubicolous polychaete and *Microdeutopus gryllotalpa,* an amphipod. Other ecotone communities of this sort but of smaller size are found elsewhere in the bay. One of these, located in the northeast corner of sector 1, contained spectacular concentrations of *Pectinaria* in 1951, numbering as many as 1500 individuals per square meter.

Intertidal Communities

As was the case with the subtidal fauna, the intertidal populations are best organized into discrete communities where there are marked differences between the kinds of substrate. In Greenwich Bay the intertidal beaches provide the following four principal kinds:

1. Sand of various degrees of sorting, often containing much decomposing organic material and black with iron sulphide a few centimeters below the surface.
2. Stones and small rocks in a matrix of sand.
3. Large rocks, wrecked boats and wharf pilings.
4. *Spartina* grass and the silt and root deposits ("peat" or "thatch") on which it grows.

The *Spartina* community is a true association of the plant-animal type. The grass forms the framework for the accumulation of silt. The silt and root deposits of many years, about 0.5 meters in thickness, occupy the upper portions of the tidal range in a number of localities about the periphery of the bay. These deposits provide excellent places for the attachment of the ribbed mussel *Modiolus demissus*, which in turn provides suitable surfaces for the attachment of *Balanus balanoides* and several species of algae. The fiddler crabs *Uca pugilator* and *U. pugnax* dig their burrows in the firm silt amid the roots of the *Spartina*.

Wherever rocks, pilings and other durable surfaces are present another community is found, the members of which are able to attach temporarily or permanently to those surfaces. The following were the most usually encountered species in Greenwich Bay:

Balanus balanoides—from high to mid tide level
Balanus eburneus—from mid tide to just below low tide
Obelia sp.—from low tide level to bottom
Urosalpinx cinerea—very near bottom
Molgula manhattensis—usually on algal fronds
Styela partita—in crevices or under rocks
Unciola irrorata—in crevices
Odostomia sp.—in crevices
Eupleura caudata—near bottom or under rocks

The members of the stony beach community live under or between the stones. The predominant members are *Mya arenaria*, *Venus mercenaria*, *Nereis succinea* and *Neopanope texana*, the last named species congregating under the larger stones. *Mya arenaria* was particularly abundant in two of these stony beaches in 1951. In a spot near the entrance to the cove in sector 1 their density was 1,000 per square meter, and in the area near the entrance to the cove in sector 10 their numbers exceeded 4,000 per square meter. In both cases the average size was small (not over 30 millimeters in length). Both populations were undoubtedly of recent year classes, although the ages were not ascertained.

By far the most extensive of the intertidal beaches are those which are primarily sandy, although scattered rocks are common even on these. Almost everywhere this sand contains sufficient silt and organic material to render it cohesive, and is quite black beneath the surface. The fauna occupies three principal strata: the surface, surface to 10-15 centimeters, and the deeper layers to about 100 centimeters. Longitudinal zonation paralleling the shoreline is also evident. The discontinuous distribution of many species produces a variability in the composition of the community, dividing it irregularly into lesser units or faciations.

The sand-beach community is continuous with the subtidal sand community, composed for the most part of the same species. *Mya arenaria*, the anthozoan *Sagartia modesta*, and the protochordate *Dolichoglossus kowalevskii* are more characteristic of the intertidal flats, however.

The interior and more protected parts of the shoreline are provided with the greatest variety and numbers of organisms. This is especially true along the western shore and in the two western corners of the bay. *Gemma gemma* and *Nassa obsoleta* are present there in enormous numbers, and a substantial spatfall of *Venus mercenaria* was found on most parts of the shore each year. The most intensive digging of interdial *Venus* by amateur and commercial diggers takes place along the western and northwestern beaches.

The eastern half of the northern shore and the stretch of shore to the east of the point in sector 8 are relatively barren, probably because they are exposed to the southeast and northeast storm waves.

DISCUSSION

In the preceding paragraphs the distribution of the various invertebrate bottom populations has been described. It now remains to interpret this distribution as fully as possible on the basis of the information available. The assumption is made that distribution of species (hence the composition of communities) is the result of several external agencies acting upon a variety of physiological systems. The importance of substrate in this respect has already been mentioned. Other agencies which might be cited are food supply, water movements, tidal exposure, temperature and salinity, although these last two items are probably less influential in Greenwich Bay than elsewhere, since they are relatively uniform. The important physiological properties of the organisms which these external agencies react are: food requirements and feeding mechanisms; the manner of reproduction and the nature of their developmental history; and the relative tolerance to exposure and to other variations in the marine climate.

Substrate determines the composition of the community in very evident fashion in separating attaching from burrowing species. Among the creeping, burrowing or tubicolous organisms, the relationships and preferences are more subtle. On the basis of data collected in 1952, including sediment analysis, it was observed that there were fewer species in muddy and silty sediments than in sandy sediments. Table I shows the number of species collected from a total of five stations in the vicinity of each of twelve localities where sediment samples were analyzed. The quality of the sediment itself may be only partly responsible for the population present. For instance, the fewer species present in fine silty mud may be the result of the high concentration of hydrogen sulphide characteristic of this kind of sediment in Greenwich Bay.

Where large amounts of shell and shell fragments are present, protection is afforded for small creeping and burrowing species. The mud crab *Neopanope texana,* often found in oyster beds, is rather secretive in its habits and finds ideal hiding places among the clusters of shells. *Nereis succinea,* abundant in shelly sediments, undoubtedly find such a habitat protective, since they probably feed on the surface of the sediment at times, and on a smooth, uniform bottom they would lie quite exposed. This feeding habit has not been demonstrated in *Nereis succinea,* but it is very characteristic of a near relative, *Nereis virens.*

Most animals inhabiting permanent burrows, e.g. *Mya, Ensis, Glycera, Nereis, Squilla,* and *Upogebia,* require the sediment to be sufficiently firm so that the walls of the burrow do not collapse. Few burrowers of this sort are found in very fluid mud or in loose, well-sorted sand. In situations where those kinds of sediments occur in Greenwich Bay, the deeper strata are more compact than those on the surface, so that deep burrowers like *Squilla* in mud or *Ensis* in sand are able to inhabit many places where surface sediments are relatively unstable.

There are other properties of sediments such that growth and development in one kind are more favored than in another. Pratt (1953) and Swan (1952) have shown better growth of *Venus* and *Mya* in sandy sediments than in mud. Some of these properties of sediments are rather obscure. Wilson (1951) found that a species of polychaete will metamorphose only in sand from a certain locality, and will fail to do so in other sand artificially graded to have the same particle size composition. Other studies by Wilson (1934) and Day and Wilson (1934) provide evidence that certain kinds of sediments are more favorable than others for the metamorphoses of the polychaetes *Notomastus* and *Scolicolepis.*

The most conspicuous direct biological relationship between organisms in a marine environment is that concerned with feeding and food supply. The food relationships of marine invertebrates are but sketchily understood. Blegvad (1914) made a comprehensive study of the feeding habits of a large number of European boreal species, and more recently the physiology and mechanisms of feedings in invertebrates have been investigated by Yonge (1928), MacGinitie (1941, 1949) and others. However, the extent to which information regarding strictly European and other alien species can be safely applied to the present study is limited.

Experimental work on the predatory activities of three common invertebrates from Greenwich Bay is currently being conducted by the U. S. Fish and Wildlife Service, with particular attention being paid to their effects on juvenile *Venus. Eupleura caudata, Urosalpinx cinerea* and *Neopanope texana* have been found to be very destructive to young bivalves. *Urosalpinx* is intertidal in Greenwich Bay except where present among exposed beds of molluscs such as *Crepidula fornicata* and *Anomia simplex. Eupleura* is broadly distributed and does not necessarily congregate where young *Venus* are numerous, but in both 1951 and 1952 the greatest numbers of them appeared in sector 10 where newly set bivalves of several species were abundant. The fact that 34 percent in 1951 and 36 percent in 1952 of all juvenile *Venus* taken in the samples were drilled indicates the extent of predation by predaceous snails, particularly *Eupleura,* since this species is more widely distributed. Drilling is most destructive to the 2-7 millimeter size group of *Venus,* and those above 15 millimeters are seldom attacked. Other important predatory species are *Limulus polyphemus,* the horseshoe crab; the portunid crabs *Callinectes sapidus* and *Ovalipes ocellatus;* the spider crab *Libinia emarginata;* and the gastropods *Polynices duplicata* and *Busycon canaliculatum.*

Animals which feed largely as scavengers are particularly abundant in the shallow water close to shore, where organic debris is washed in by the waves or is stirred up from the sediment. Crabs, hermit crabs, the sand shrimp, and *Nassa* are typical scavengers. Organic detritus also forms a substantial part of the diet of many organisms, which may filter it from suspension in the water along with plankton or may feed on bottom deposits. The digestive tracts of *Ampelisca spinipes* and *Pectinaria gouldii* were found to contain large amounts of both mineral and organic detritus suggesting that these species feed upon bottom deposits. They are certainly most abundant where the organic content of the sediment is high.

Tentacled worms, many bivalves, and *Crepidula* feed upon suspended organic particles (Yonge 1928; MacGinitie 1941; Coe and Fox 1944). A requisite for this kind of feeding is sufficient water circulation to keep the food material in suspension and a supply of it constantly available. In Greenwich Bay there is a greater number of species of suspension feeders to be found in sediments which by their composition (i.e. high percentage of coarse particles) are indicative of good circulation. Some bivalves, for instance species of *Macoma*, feed on the organic deposits which lie on the surface of the sediment, using the incurrent siphon as a sort of vacuum cleaner. For such species the sediment must not be too well washed, and it is not surprising that *Macoma tenta* is an inhabitant of the muddy sediments in Greenwich Bay.

Life histories, although quite insufficiently understood for most species, are very important in determining the ultimate distribution of organisms as Thorson (1946) has emphasized with abundant examples. Distribution can be said to result from two kinds of processes: those of dispersal and those of selection. Selection may be active when the site for development is selected by the individual and passive when the organism survives or fails to survive in the location where it is cast. Shelford (1915) in discussing these processes has used the expressions "dissemination" and "selective survival." Wilson (1934, 1951, 1953), Smith (1952), Thorson (1946) and other workers have shown that active selection of a suitable site for development my the young organism occurs more commonly than might be supposed.

A few examples may be cited which illustrate the relationship of life history to distribution of species in Greenwich Bay. *Balanus*, *Anomia*, *Crepidula*, *Modiolus* and *Molgula* all have a pelagic larval period during which they may be dispersed rather broadly. Since each species requires a certain type of firm substrate upon which to metamorphose and develop, and since substrata of suitable character occur only here and there in Greenwich Bay, the distribution of these species is limited accordingly.

Many species with a pelagic larval period but for which the substrate requirements are less critical than for those mentioned above, do not settle uniformly over all parts of the bottom ostensibly suitable for their development. Young bivalves, such as *Venus*, *Mya*, *Mulinia* and *Ensis*, may colonize different areas in the bay each year. This may be partly due to concentration of the larvae by physical forces (e.g. currents), but in the case of *Mya arenaria* (and perhaps other species) it has been shown (Smith 1952) that the newly settled juveniles move about of their own accord and may actively select the most favorable localities in which to develop.

By contrast, the distribution of *Ampelisca* is extensive and continuous. This amphipod does not have a pelagic period but develops within the brood pouch of the female parent. For this reason the same area is populated year after year by successive generations, and while its extent may change or increase, this phenomenon occurs by extension of its periphery rather than by seeding in of scattered patches.

Obviously those species which are active as adults are affected but slightly by their dispersal as larvae, and their distribution is governed by their active selection of places which are most suitable.

Nassa obsoleta congregates in shallow water, especially near the outflow of tidal creeks, where erosion constantly exposes organic material on which they feed. *Neopanope*, secretive by nature, gravitates to shelly or stony places where crevices are available in which to hide. *Eupleura* seeks out patches of young bivalves on which to feed.

CONCLUSIONS

The present investigation has made clear several facts about the bottom invertebrate populations in Greenwich Bay.

1. The distribution of nearly all species collected is not uniform, but rather irregular and discontinuous. Many of these irregularities are due to differences in the nature of the substrate and other obvious controlling factors, but for others the causes are not apparent.

2. There are certain regions with a general paucity of all animal life. These regions appear to remain poor in this respect over long periods of time and are consistently avoided by clam fishermen. The largest barren region of this sort is in the muddy central part of the bay. Fig. 7 illustrating the distribution of *Venus* shows this region rather clearly.

Other localities support a relatively large variety of species and many individuals. The *Crepidula* community is a good example of one of the more productive areas in the bay. Although it supports somewhat less than the bay average in number of species, the species there whose numbers exceed those in any other part of the bay are comparatively large in size and therefore the biomass is substantially higher than elsewhere.

3. Different kinds of animal communities are present, each with its characteristic species. Except in a few cases where interaction between species was apparent, the organization of a community seemed to be the result of several environmental factors reacting with a variety of physiological systems. Since sufficient information about either of these sets of variables is unavailable to analyze the distributions fully, the organization of the community appears fortuitous to the observer. Artificial systems of describing the observed organization as used by some authors have been avoided since these systems may not necessarily be related to the biological organizations, and would serve no useful purpose.

4. No association between *Venus mercenaria* and other species is reflected by their patterns of distribution. There is a similarity in the distributions of *Nereis* and *Venus* as shown in Figures 6 and 7, but the centers of population do not coincide exactly.

5. A few species, because of their abundance and broad distribution within the bay may be called characteristic of it. Each of the following species was collected in more than 100 samples:

Venus mercenaria
Ampelisca spinipes
Corophium cylindricum
Podarke obscura
Pectinaria gouldii
Nereis succinea
Spiochaetopterus oculatus
Heteromastus filiformis

The presence of characteristic species such as these is as much a property of an area under study as its salinity, temperature, or other physical property, and as such should have a certain value in appraising the area and comparing it to others. In some respects, characteristic organisms may actually be better indicators than measured chemical or physical properties if they respond to extremely subtle or un-measurable properties of the water.

Of those species listed, a few are extremely ubiquitous and their presence may signify nothing. Others, on the other hand, are less universally distributed. *Venus mercenaria* is such a species, as is *Pectinaria gouldii*, both of which are but intermittently distributed on the New England coast. Within the bay, there is no particular relationship between the distributions of these two species. On the New England coast as a whole, their distribution coincides rather closely. Thirteen separate localities between Portland, Maine, and Milford, Connecticut, were examined by the authors and of these, six had populations of both *Venus* and *Pectinaria*, six had no populations of either species, and one had a population of *Venus* but no *Pectinaria*.

Records of other authors (Verrill 1872; Sumner, Osburn and Cole 1911; Allee 1923; Lee 1944; Dexter 1947) although not explicit on this point, nevertheless indicate for the particular regions studied that *Venus* is present where *Pectinaria* (*Cistenides* of some authors) is present and conversely absent where *Pectinaria* is absent.

Of particular interest is the city of Salem, Massachusetts, where the only recent population of *Venus mercenaria* between Boston and Portland, Maine, has been observed. The only record known to the authors of *Pectinaria gouldii* in the same section of coastline is also from this locality.

The above information is, of course, too scanty to provide definite conclusions concerning the patterns of distribution of these two species, and it is not, strictly speaking, a part of the Greenwich Bay project. It does, however, suggest the possibilities that certain species or combinations of species might be useful as indicators of localities suitable for another species of more value or importance. In view of the interest in clam farming and transplanting of clams, such indicators could be of considerable value.

To provide sufficiently significant information about the distribution of marine organisms to be useful in such applications, further detailed studies of many tidal flats and shallow bays along the coast would be very desirable.

SUMMARY

As a part of a survey of the hard clam (*Venus mercenaria*) in Greenwich Bay, Rhode Island, a study of the other bottom fauna inhabiting the area was made during the summers of 1951 and 1952. The objects of this study were:

(1) to describe the bottom invertebrate population,
(2) to find out whether any organisms were particularly associated with *Venus* within the bay,
(3) to determine whether localities which had

also barren of other forms of life as well, and

(4) to find out which species were characteristic of a good clam-producing area with the idea that this information might be useful in appraising other potential clam producing areas.

The population as a whole could be divided into three major communities each based largely on the nature of the bottom sediment: a mud-bottom community dominated by *Ampelisca spinipes;* a sand-bottom community and a shell-bottom community dominated by *Crepidula fornicata. Venus* was found to be present in all three communities. No particular association between *Venus* and other organisms was apparent in their respective distributions, and joint occurrence of that species with others appeared to be a matter of chance.

Several species are sufficiently abundant and widely distributed in the bay to be called characteristic. Predominant among these are *Venus mercenaria, Ampelisca spinipes, Nassa obsoleta, Pectinaria gouldii,* and *Spiochaetopterus oculatus.* A brief analysis of collections, personal observations and available published records of the occurrence of *Venus* and *Pectinaria gouldii* on the New England coast was made, and it was found that *Pectinaria* was nearly always present in *Venus* areas, and absent where *Venus* was absent. There was not, however, any particular relationship in the distribution of these two species within Greenwich Bay.

The central part of the bay was found to be consistently more barren of living material and certain ecotone areas more rich in species and individuals than were the other parts. The relative paucity of life in the center was assumed to be due to the soft, silty character of the sediment and the high levels of hydrogen sulphide present in them.

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Appendix

TABLE 1. Complete list of species collected or observed in Greenwich Bay, R. I. during 1951 and 1952

PORIFERA: *Cliona celata* Grant; *Microciona prolifera* Verrill.

COELENTERATA: *Clytia* sp.; *Halecium* sp.; *Obelia* sp.; *Sagartia modesta* Verrill.

NEMERTEA: *Cerebratulus lacteus* Leidy; *Micrura* sp.

BRYOZOA: *Amathia dichotoma* Verrill; *Bowerbankia* *gracilis* Leidy; *Lepralia pallasiana* Moll; *Membranipora* sp.; *Schizoporella* sp.

ECHINODERMATA: *Asterias forbesi* Desor; *Synapta inhaerens* Muller.

ENTEROPNEUSTA: *Dolichoglossus kowalevskii* Spengel.

TUNICATA: *Molgula arenata* Stimpson; *Molgula manhattensis* DeKay; *Styela partita* Stimpson.

ANNELIDA (POLYCHAETA): *Ampharete* sp.; *Amphitrite ornata* Leidy; *Arabella* sp.; *Capitellides* sp.; *Clymenella torquata* Leidy; *Diopatra cupraea* Bosc; *Drilonereis longa* Webster; *Eteone* sp.; *Eumida sanguinea* Oersted; *Glycera americana* Leidy; *Glycera dibranchiata* Ehlers; *Haploscoloplos fragilis* Verrill; *Harmathoe extenuata* Grube; *Heteromastus filiformis* Claparede; *Hydroides uncinata* Philippi; *Lepidonotus sublevis* Verrill; *Lumbrinereis tenuis* Verrill; *Maldanopsis elongata* Verrill; *Nephthys incisa* Malmgren; *Nephthys picta* Ehlers; *Nereis caudata* Delle-Chiaje; *Nereis succinea* Frey & Leuckart; *Pectinaria gouldii* Verrill; *Pherusa affinis* Leidy; *Phyllodoce* sp.; *Pista* sp.; *Podarke obscura* Verrill; *Polydora ligni* Webster; *Polygordius* sp.; *Sabella microphthalma* Verrill; *Sabellaria vulgaris* Verrill; *Scolelepides viridis* Verrill; *Spio setosa* Verrill; *Spiochaetopterus oculatus* Webster; *Sthenelais boa* Johnston; *Streblospio benedicti* Webster; *Tharyx acutus* Webster.

ARTHROPODA: *Ampelisca macrocephala* Lilljeborg; *Ampelisca spinipes* Boeck; *Apherusa* sp.; *Balanus balanoides* Linnaeus; *Balanus eburneus* Gould; *Callinectes sapidus* Rathbun; *Corophium cylindricum* Say; *Crago septemspinosus* Say; *Cylindroleberis mariae* Baird; *Edotea triloba* Say; *Erichsonella filiformis* Say; *Libinia emarginata* Leach; *Limulus polyphemus* Linnaeus; *Microdeutopus gryllotalpa* Costa; *Neopanope texana* Say; *Ovalipes ocellatus* Herbst; *Oxyurostylis smithi* Calman; *Pagurus longicarpus* Say; *Pagurus pollicaris* Say; *Palaemonetes vulgaris* Say; *Pinnixa sayana* Stimpson; *Squilla empusa* Say; *Uca pugilator* Bosc; *Uca pugnax* Smith; *Unciola irrorata* Say; *Upogebia affinis* Say.

MOLLUSCA: *Anomia simplex* d'Orbigny; *Arca* sp.; *Busycon canaliculatum* Linnaeus; *Crepidula convexa* Say; *Crepidula fornicata* Linnaeus; *Crepidula plana* Say; *Cylichna oryza* Totten; *Ensis directus* Conrad; *Eupleura caudata* Say; *Gemma gemma* Totten; *Littorina litorea* Linnaeus; *Lyonsia hyalina* Conrad; *Macoma tenta* Say; *Mitrella lunata* Say; *Modiolus demissus* Lamarck; *Mulinia lateralis* Say; *Mya arenaria* Linnaeus; *Mytilus edulis* Linnaeus; *Nassa obsoleta* Say; *Nassa trivittata* Say; *Nucula proxima* Say; *Odostomia* sp.; *Ostrea virginica* Gmelin; *Pandora gouldiana* Dall; *Pecten irradians* Lamarck; *Petricola pholadiformis* Lamarck; *Pitar morrhuana* Linsley; *Polynices duplicata* Say; *Tellina tenera* Say; *Tornatina canaliculata* Say; *Urosalpinx cinerea* Say; *Venus mercenaria* Linnaeus.

[APPENDIX]

TABLE 2. The distribution and abundance of certain species in Greenwich Bay as indicated by the average number of individuals per square meter in each sector, 1951

Species	Sector										
	1	2	3	4	5	6	7	8	9	10	11
Venus mercenaria	9	3	5	12	4	3	2	5	22	7	6
Mya arenaria	22	2	4	4	4	2	0	1	0	0	0
Tellina tenera	0	0	1	0	1	0	0	2	1	5	1
Mulinia lateralis	0	0	2	2	10	0	0	10	0	6	10
Petricola pholadiformis	6	2	1	6	2	0	0	0	0	4	1
Ensis directus	0	0	0	0	0	0	1	3	1	7	9
Anomia simplex	0	0	0	1	0	1	10	0	76	1	0
Macoma tenta	0	0	1	12	0	0	0	0	0	1	0
Nucula proxima	0	0	1	12	0	5	2	6	0	0	0
Eupleura caudata	10	4	7	8	12	4	8	12	10	6	12
Nassa obsoleta	160	7	82	40	216	22	12	108	40	60	34
Urosalpinx cinerea	3	0	2	0	2	1	0	1	5	0	0
Tornatina canaliculata	20	20	22	40	16	38	2	28	0	2	2
Crepidula fornicata	1	0	0	0	0	0	10	1	46	5	2
Nereis succinea	20	0	8	26	12	12	54	10	66	12	10
Pectinaria gouldii	120	20	38	76	86	70	60	130	12	12	28
Haploscoloplos fragilis	26	0	4	6	6	3	3	3	2	13	7
Spiochaetopterus oculatus	3	20	5	16	8	10	4	12	2	64	12
Spio setosa	4	2	0	0	5	0	0	2	2	9	3
Streblospio benedicti	*	*	*	*	*	*	*	*	*	*	*
Polydora ligni	0	4	3	0	0	4	0	0	0	5	1
Tharyx acuta	20	60	28	10	14	10	2	4	0	0	6
Heteromastus filiformis	2	4	1	6	2	0	0	0	0	0	1
Podarke obscura	20	120	94	26	28	124	6	4	0	0	0
Glycera dibranchiata	1	2	2	2	2	1	2	6	4	3	10
Harmathoe extenuata	0	0	7	0	3	10	0	0	0	0	0
Diopatra cupraea	3	0	0	0	3	0	0	1	2	1	2
Ampelisca spinipes	*	*	*	*	*	*	*	*	*	*	*
Microdeutopus gryllotalpa	*	*	*	*	*	*	*	*	*	*	*
Corophium cylindricum	*	*	*	*	*	*	*	*	*	*	*
Pagurus longicarpus	0	0	0	0	2	0	0	0	1	6	2
Neopanope texana	0	0	0	1	2	0	3	0	4	1	0
Libinia emarginata	0	0	0	0	0	0	1	0	4	1	1

[APPENDIX]

TABLE 3. The distribution and abundance of certain species in Greenwich Bay as indicated by the average number of individuals per suare meter in each sector, 1952

Species	Sector										
	1	2	3	4	5	6	7	8	9	10	11
Venus mercenaria	7	2	1	24	1	1	4	2	12	5	5
Mya arenaria	0	0	1	0	0	1	0	0	16	10	51
Tellina tenera	0	0	0	0	2	0	1	0	3	27	[illegible]
Mulinia lateralis	2	0	1	1	2	1	3	80	3	52	95
Petricola pholadiformis	0	0	0	2	0	0	1	7	22	4	186
Ensis directus	0	0	0	0	2	0	0	0	4	31	17
Anomia simplex	1	0	0	18	0	0	0	9	39	1	2
Macoma tenta	4	1	1	17	4	32	34	238	0	0	0
Nucula proxima	0	0	0	0	0	2	4	16	0	0	0
Eupleura caudata	3	2	3	3	9	5	4	164	3	3	21
Nassa obsoleta	96	76	188	85	282	14	4	7	62	4	1
Urosalpinx cinerea	1	0	1	1	0	0	0	0	6	1	1
Tornatina canaliculata	20	48	48	34	6	18	3	34	0	5	30
Crepidula fornicata	0	0	0	8	0	0	1	7	115	9	1
Nereis succinea	15	1	0	12	20	9	50	26	206	47	93
Pectinaria gouldii	32	0	4	35	31	46	28	266	29	38	100
Haploscoloplos fragilis	7	0	1	6	10	1	1	5	12	6	52
Spiochaetopterus oculatus	54	32	30	21	111	218	172	362	28	67	13
Spio setosa	5	0	0	2	2	0	0	0	32	67	29
Streblospio benedicti	0	0	0	0	1	0	0	0	5	124	0
Polydora ligni	0	0	0	0	0	0	0	0	1	2	0
Tharyx acuta	40	40	80	12	4	9	8	7	0	27	47
Heteromastus filiformis	36	36	19	3	46	19	18	20	47	63	35
Podarke obscura	54	244	260	50	6	74	44	36	3	0	9
Glycera dibranchiata	6	3	2	2	6	5	8	15	10	30	45
Harmathoe extenuata	0	0	0	0	0	0	0	0	3	1	1
Diopatra cupraea	0	0	0	0	0	0	0	0	1	1	2
Ampelisca spinipes (X10)	132	318	366	138	42	740	524	978	101	238	571
Microdeutopus gryllotalpa	1	0	0	0	0	7	56	62	3	22	92
Corophium cylindricum	10	54	82	20	0	73	64	700	9	103	92
Pagurus longicarpus	0	0	0	0	0	0	0	0	1	21	3
Neopanope texana	0	0	0	0	0	0	2	0	21	2	1
Libinia emarginata	0	0	0	0	0	0	0	0	24	52	0

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NOTES ON THE RESPIRATION OF SMALL *REMORA REMORA*.—On a recent equatorial cruise of the U. S. Fish and Wildlife Service vessel HUGH M. SMITH numerous specimens of the white-tipped shark *Pterolamiops longimanus* (Poey) were taken by handline. On March 22–23, 1956, at approximately 1°N. latitude and 140°W. longitude, two six-foot sharks bearing small sucker fish, *Remora remora* (Linnaeus), were landed. Three of the latter were transferred to a large plastic tub immediately after the sharks were captured. The tub was supplied with running sea water pumped directly from the ocean; thus the water had essentially the same temperature and dissolved oxygen characteristics as the natural environment. Despite these supposedly favorable conditions the remoras consistently evidenced peculiar respiratory behavior, not all of which could be ascribed to the shock of capture, handling, or confinement.

Upon being placed in the tub each remora at first swam slowly about, but very soon attached its sucking disc to the side of the tub just at the water's edge. The mouth and part of the head were exposed to the air, and respiratory movements consisted of rapid gulps in which some air was taken in and some water forcibly expelled from the mouth. The fish could be manually moved down the side of the tub with difficulty but usually returned quickly to the surface when not restrained. In those instances where fish remained submerged, their opercular breathing movements ranged from 135 to 244 expirations per minute (Table I). This rate appears to be relatively high, for the highest value in Norman's list (1949, A History of Fishes, p. 43) of rates for various species is 150 respirations per minute for the minnow *Phoxinus* and the stickleback *Gasterosteus*.

By chance it was found that a jet of water aimed at the remoras' open mouths caused the respiratory rate to decrease markedly, and the fish could then be pushed down the side of the container with little difficulty. They remained submerged as long as water was flowing over them, but rheotaxic behavior was not indicated since they did not orient themselves to the current when its direction was changed. By varying the rate of water flow a point was found at which the fish ceased all opercular movements and other external signs of respiration. Water was administered by a length of quarter-inch glass tubing placed about an eighth of an inch in front of the fish's mouth and connected to a faucet by rubber tubing. The rate of flow could be controlled quite easily and was measured by timing the interval required to fill a 1000 ml. volumetric flask. Several tests were made to determine the rate of flow necessary to stop external respiratory movements, and the results are presented in Table I. Of the various tests, numbers 3 to 8 are not given further consideration, as changing water temperature and other variables invalidated them for comparative purposes.

With flowing water, the volume of flow required to stop respiratory gill movements increased with increase in fish size (mean values of tests 1 and 2). Without flowing water, the number of respirations per minute decreased with increase in fish size. A measure of the interrelationship between these two phenomena can be obtained by dividing the flow rate (in ml. per minute) by the respiratory rate (in respirations per minute) giving an index in terms of milliliters of water per single respiration (Table I column 5). These values are only relative since not all water aimed at the fish's mouth is presumed to enter. When the mean milliliter-per-respiration values (tests 1 and 2) are plotted against fish volume an almost perfect linear relationship is apparent This admittedly should obtain because respiratory volume varies with the size of the branchial and buccal cavities, which in turn is dependent on the size of the fish. When respiratory volume is expressed as a percentage of fish volume the mean values of all three fish (tests 1 and 2, column 8) are 40 percent, this again being only a relative figure Assuming that only half of the water from the jet actually enters the mouth, and that the respiratory rate in standing water is about 200 respirations per minute, then in one minute a small remora would pass a quantity of water equivalent to 40 times its own volume over its gills, certainly a remarkable achievement.

TABLE I

RESPIRATORY DATA FOR *Remora remora*

Fish A, B, and C were tested simultaneously in Test 1 and again in Test 2.

1	2	3	4	Rate of water flow required to stop opercular movements			
Fish, with its andard length and displacement volume	Test No.	Water temperature in degrees F.	Respirations per minute with no current applied	5 In milliliters per minute	6 In miles per hour[1]	7 In ml. per respiration[2]	8 Ml. per respiration as percent of fish volume[3]
A 81 mm. 7.1 ml.	1 2	76.8 76.8	244 244	638 747	0.75 0.88	2.6 3.1	37 44
	Mean		244	692	0.82	2.8	40
B 98 mm. 11.9 ml.	1 2	76.8 76.8	236 236	1143 1161	1.34 1.37	4.8 4.9	40 41
	Mean		236	1152	1.36	4.8	40
	3	78.6	200	—	—	—	—
	4	77.0	210	—	—	—	—
	5	77.0	150	1186	1.40	7.9	66
	6	77.1	147	1215	1.43	8.3	70
	7	77.2	135	1136	1.34	8.4	71
	8	76.3	217	1095	1.29	5.0	42
	Grand mean		191	1156	1.36	6.6	55
C 103 mm. 14.5 ml.	1 2	76.8 76.8	203 203	1357 1007	1.60 1.18	6.7 5.0	46 34
	Mean		203	1182	1.39	5.8	40

[1] Calculated from flow per unit time through quarter-inch glass tubing.
[2] Calculated by dividing the figure in column 5 by that in column 4.
[3] The figure in column 7 as a percent of the volume given in column 1.

The fact that when remoras are not provided with an artificial stream of water the breathing rate is higher for small individuals suggests that smaller specimens either require more oxygen, have less efficient gills, or relatively smaller buccal and branchial cavities. It has already been demonstrated that the relative amount of water passed per resting respiration is exactly proportional to fish volume, a not unexpected situation, eliminating one possible reason for the higher rate of small fish. Of the remaining two, less efficient gills or greater respiratory need, the latter is more attractive as generally metabolic rates are higher in smaller individuals of a given species.

It is difficult to state how much the exciting and debilitating effects of capture and confinement contributed to the behavior outlined above. The first remora taken (Fish B) was confined for 28 hours and apparently was in good condition at the end of this period. The other two were captured 20 hours after Fish B, and were found dead in the tub after 21 hours of confinement. They were under observation for the first 15 hours of this period and appeared normal thoughout that time; they died during the night when the supply of circulating sea water was shut off. All three fish were in a state of excitation when first placed in the tub but appeared to adjust to the new environment quite rapidly.

Several extrapolations from the tabulated data and the described behavior are worthy of comment. It would appear that remoras may obtain other benefits from shark-riding than just transportation and the chance to dine with a shark. Their aquarium behavior suggests that they may require rapidly moving water to convey dissolved oxygen to their gills, and that they have become so adjusted to this service that an inordinate expenditure of energy (in the form of rapid respiratory movements) is required when in quiet water. Some evidence for this is the fact that Fish B survived a night in circulating sea water whereas Fish A and C died the next night when the water was shut off (Fish B had been preserved in the meantime).

One would expect this limitation to be reflected in either the respiratory anatomy or physiology of *Remora*. Apparently little is known about the physiology of echeneids. Gray (1954, Biol. Bull., 107(2) : 221) has calculated the gill area of *Echeneis naucrates* and ranks the species ecologically with the cutlass fish (*Trichiurus*), the butter fish (*Poronotus*), and other "fishes of moderate activity" living around piers or spending some time resting on the bottom.

Willem (1951, Bull. Inst. Roy. Sci. Nat. Belg., 27(8) : 1–6) noted the unusual development of the respiratory musculature of *Echeneis naucrates* and concluded that the species must pass a considerable volume of water with each expiration which is certainly in accordance with the present findings for *Remora*. Gross examination of the preserved experimental specimens and others caught subsequently revealed no outstanding branchial differences between *Remora* and more generalized fishes.

From these lines of evidence *Remora remora* appears to be somewhat comparable to the Atlantic mackerel (Hall, 1930, Am. Jour. Physiol. 93(2): 420) in that it requires a swift passage of water over its gills and cannot cope with confinement in still water. On the other hand, various echeneids have been maintained in the Honolulu Aquarium for several weeks without difficulty (personal communication from Spencer Tinker, the Director).

When the rate of water flow required to stop opercular movements is expressed in miles per hour, a very peculiar result is obtained (Table I, column 6). It would superficially appear that larger remoras require faster currents than smaller specimens, in contrast to the measurements of respiratory rate and the situation found in nature. In my experience small echeneids are nearly always found attached to moving objects whereas the largest specimens seen were three-foot *Echeneis naucrates* found free-swimming around piers in the Marshall Islands. The conflict between these observations stems from the fact that computed water speed was derived from flow through glass tubing and not through the fish's buccal cavities. The cross-sectional area of the latter increases with increasing fish size whereas that of the former is constant. Water speed decreases upon leaving the tube orifice and entering the relatively large buccal cavity, the decrease becoming greater with increasing fish size. The speed of water flow calculated for the smallest remora (Fish A) most closely approximates the actual speed through the mouth, whereas those for Fish B and C are increasingly in error.

A final question has to do with whether the speed of flow determined for Fish A can be used as an approximation of the average swimming speed of white-tipped sharks. Efforts to time these sharks as they circled the drifting HUGH M. SMITH were not particularly successful in that the sharks often loitered over garbage, pursued irregular courses, or disappeared from view. A speed of about one mile an hour is certainly within the capabilities of *Pterolamiops longimanus* and may well approximate its normal cruising speed.—DONALD W. STRASBURG, *U. S. Fish and Wildlife Service, Honolulu, Hawaii.*

NUISANCE OR RESOURCE?

SHARKS

OF THE CENTRAL PACIFIC

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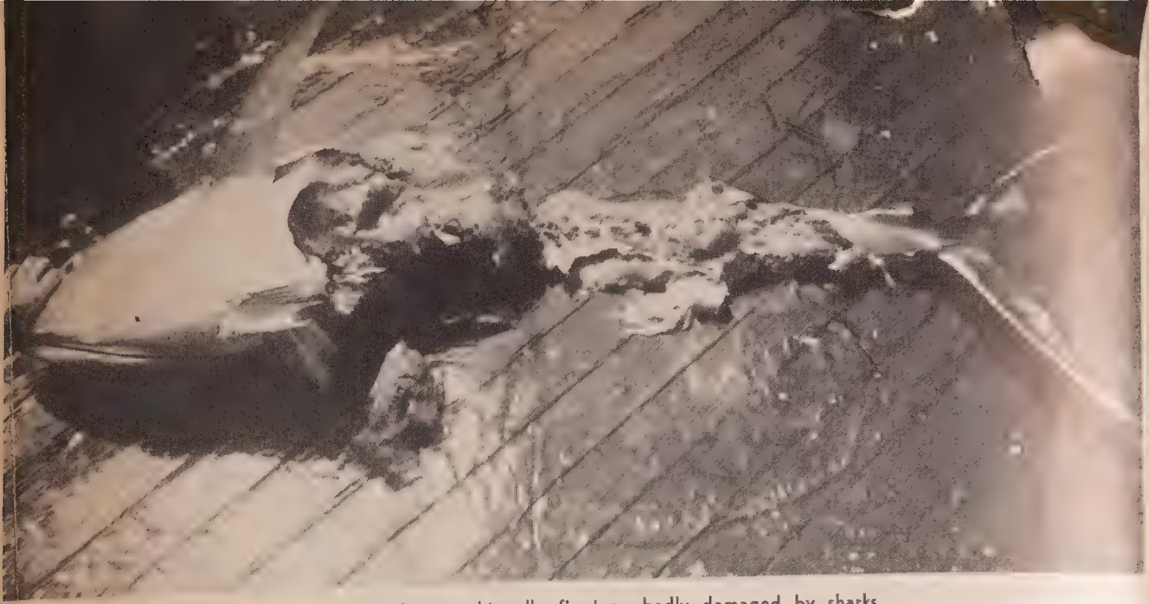

Figure 2.—Longline-caught yellowfin tuna badly damaged by sharks.

SHARKS OF THE CENTRAL PACIFIC...

Nuisance or Resource?

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IN MANY parts of the Pacific Ocean, especially in the tropics, fishing and baiting operations are either hampered or made dangerous by the presence of sharks. The shark nuisance may result in loss or damage to the catch, time wasted in untangling or repairing gear, and in rare cases in injury to personnel.

For the past several years the Pacific Oceanic Fishery Investigations of the U.S. Fish and Wildlife Service, with headquarters in Honolulu, has been using longline gear to sample the tuna resources of the Pacific. During the period 1952-1955, POFI longlined from just south of the Aleutian Islands to the Society Islands, and from the west coast of the United States to 180°, the International Date Line.

Besides tuna, marlin, and a few other food fish the catch contained over 6,000 sharks. Of these, about

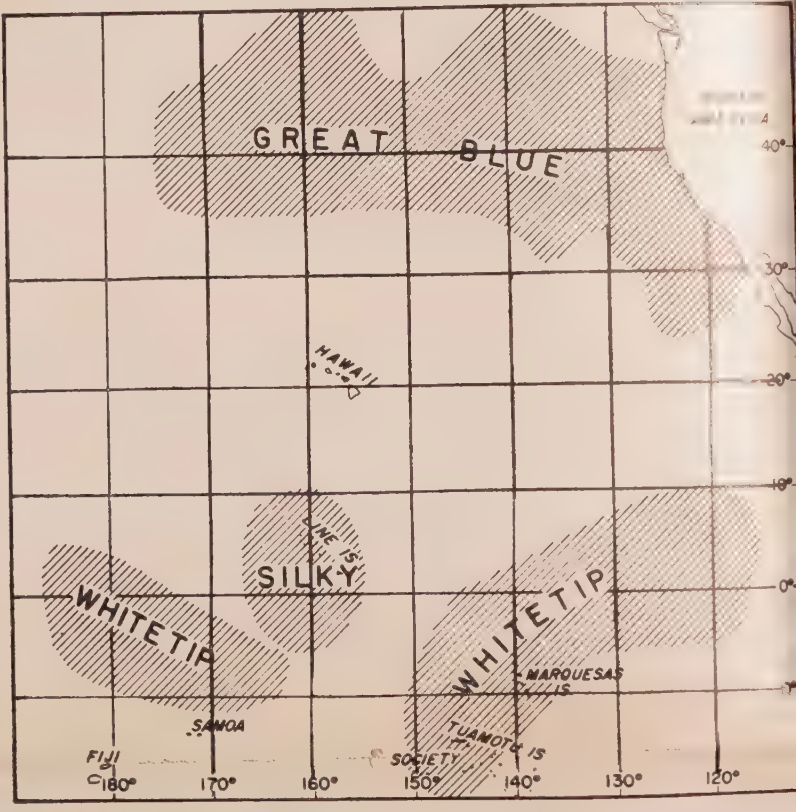

Figure 1.—The central Pacific Ocean showing regions in which FWS found sharks to abundant and indicating the dominant species.

THE MORPHOLOGY AND LIFE-HISTORY OF THE DIGENETIC TREMATODE, MICROPHALLUS SIMILIS (JÄGERSKIÖLD, 1900) BAER, 1943

HORACE W. STUNKARD

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THE MORPHOLOGY AND LIFE-HISTORY OF THE DIGENETIC TREMATODE, MICROPHALLUS SIMILIS (JÄGERSKIÖLD, 1900) BAER, 1943[1]

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Although significant observations had been reported earlier, the first complete life-histories of microphallid trematodes were worked out by Cable and Hunninen (1940) and Rankin (1940b). M'Intosh (1865) had described and figured larval worms from the tissues of the green crab, *Carcinides maenas* (Linnaeus), taken at St. Andrews, Scotland, but the life-cycles of trematodes were quite unknown at the time and M'Intosh described the structures as eggs, each of which contained a tiny worm that he surmised became a sexually mature distome in "such fishes as the Cotti, Gadi, and others," which feed on the crustaceans. He reported a specimen of *Cottus bulbalis,* about a foot long, with (p. 204) "two entire specimens of *Carcinus maenas,* each upwards of two inches across the carapace, in its stomach, besides the partially digested debris of others." His descriptions and figures identify the worms as members of the genus *Microphallus* and with considerable certainty as *M. similis* (Jägerskiöld, 1900). Although measurements were not given, his Figure 5 of an excysted specimen shows the suckers to be of approximately equal size and the "small globule" (seminal vesicle) anterior to the acetabulum, together with the size of the gonads, evidence full development of the metacercaria.

Levinsen (1881) described adult trematodes from the eider duck, *Somateria molissima,* taken at Egedesminde, Greenland, as *Distoma pygmaeum* and Brandes (1889) described similar worms from *Tringa alpinus* as *Distoma claviforme.* Jägerskiöld (1900) described specimens from Swedish gulls, *Larus argentatus* and *L. fuscus,* as *Distoma pygmaeum* var. *simile.* Other species have since been described from different hosts in other parts of the world. Ward (1894) described worms from American lake-fish as *Distoma opacum* and noted their similarity to *D. pygmaeum.* The parasites occurred in *Amia calva, Ictalurus punctatus* and *Perca flavescens,* and encysted larval stages were found in the crayfish, *Cambarus propinquus.* With the dismemberment of the old genus *Distoma,* Stossich (1899) erected the genus *Levinsenia* to include *Distoma brachysomum* Creplin, 1837, *D. macrophallos* von Linstow, 1875, *D. pygmaeum* Levinsen, 1881, and *D. opacum* Ward, 1894. Lühe (1899), but not Looss (1899), as has been claimed (cf. Looss, 1902: p. 704) designated *L. brachysoma,* and Jägerskiöld (1900) proposed *L. pygmaeum,* as type of the genus *Levinsenia.* Noting differences between *D. brachysomum* and *D. opacum,* Ward (1901) named the latter species type of a new genus, *Microphallus.* In this paper he reported that the name *Levinsenia* Stossich is a homonym of *Levinsenia* Mesnil, 1897, a polychaete annelid, and that Stiles and Hassall were to propose the name *Levinseniella* to replace it. Although the paper by Stiles and Hassall did not appear until 1902, the name *Levinseniella* Stiles and Hassall in Ward, 1901 was validated with *L. brachysoma* as type. Jägerskiöld (1901), although aware of the announcement by Ward, proposed the name *Spelotrema* for the invalid name *Levinsenia,* with *S. pygmaeum* as type. Cable and Hunninen (1940), commenting on this action, wrote (p. 153), "If the law of priority should be applied to this case, *Spelotrema* Jägerskiöld, 1901 should be suppressed as a synonym of *Levinseniella* Stiles and Hassall in Ward, 1901, since Jägerskiöld stated subsequently (1904) '*Spelotrema* (= *Levinseniella*)' and therefore certainly regarded them as synonymous. His later (1907) conception of two distinct genera is valid, however, and must be accepted although he should not have retained for them names which he had regarded previously as synonyms. To suppress *Spelotrema* as a synonym of *Levinseniella,* and propose a new generic name for the species at present allocated to the genus *Spelotrema,* would probably increase rather than diminish the present confusion. For this reason, the writers are inclined to let the matter stand." As noted, *L. brachysoma* and *S. pygmaeum* are not congeneric and the characteristic features of the two genera were presented clearly by Rankin in two papers (1939, 1940a). The problem of nomenclature, stated by Cable and Hunninen, was resolved when Baer (1943) suppressed *Spelotrema* as a synonym of *Microphallus* and transferred all species from the former genus to the latter one. Baer described *Microphallus gracilis* from *Neomys fodiens* and formulated a key to thirteen members of the genus. Strandine (1943) and Rausch (1946a, 1946b, 1947) discussed morphological features and host-specificity of species in the genus *Microphallus.* Rausch and Locker (1951) described *Microphallus enhydrae* n. sp., from the sea-otter, *Enhydra lutris,* and recognized fourteen species in the genus. Stunkard (1951, 1953) described metacercariae from the horseshoe crab, *Limulus polyphemus,* and their development to sexual maturity in white mice, golden hamsters, and the herring gull, *Larus argentatus.* Although the worms agreed closely with the description of *M. claviformis* (Brandes, 1899), bionomic features seemed to preclude their allocation to that species and they were described as members of a new species, *Microphallus limuli.* Cable and Kuns (1951) erected a new genus, *Carneophallus,* and discussed the evolution and interrelationships of genera in the family Microphallidae.

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[1] The experimental work was done at the Marine Biological Laboratory, Woods Hole, Massachusetts, during the period May 1 to October 31, 1956.

Lebour (1905) reported grape-like masses of "sporocysts" in the liver of *Littorina rudis* (= *L. saxatilis*), filled with tail-less cercariae, doubled up in a curious manner. When extended, they measured 0.25 mm. in length and the figure shows them to be microphallid metacercariae. Miss Lebour regarded these larvae as identical with the encysted worms found by M'Intosh (1865) in the green crab, *C. maenas.* Brandes (1889) had suggested that the larva in the green crab is the encysted stage of *Distoma claviforme,* described by him from *Pelidna (Tringa) alpina* and *Aegialitis hiaticula.* Nicoll (1906) described specimens from the ceca and intestine of *Larus argentatus* taken at St. Andrews, Scotland, which he identified as *Levinsenia similis,* the species that Jägerskiöld (1900) had described as a variety of *Dist. pygmaeum* and (1907) raised to specific rank as type of *Spelotrema.* Nicoll noted that his specimens were somewhat larger than those of

Jägerskiöld and that worms from the ceca were larger than those from the intestine. He declared that the metacercariae from *C. maenas* are as likely to prove larvae of *S. similis* as of *S. claviforme*. The following year, Nicoll (1907) described the worms from *L. argentatus* at St. Andrews as a new species, *Spelotrema excellens,* distinct from *S. similis.* Other specimens from *Pelidna alpina, Totanus calidris* and *Aegialitis hiaticula* were described as a new species, *Spelotrema feriatum.* He gave a redescription of *S. claviforme* and in a footnote stated that the larvae from *C. maenas* are larger than the adults of *S. claviforme* and must belong to another species, perhaps *S. excellens.* The smaller metacercariae described by Lebour (1905) from the liver of *Littorina rudis* were suggested as the encysted stage of *S. claviforme.* Lebour (1908) designated the metacercaria from *C. maenas* as *Cercaria carcini* and recognized the difficulty of relating the larval forms of *Spelotrema* with any known adults. Nicoll and Small (1909) examined crabs at Millport on the Scottish west coast during August, 1908. They found three of four *C. maenas* and one of five *Cancer pagurus* infected with encysted metacercariae which they identified as a species of *Spelotrema,* most probably *S. excellens* Nicoll. At St. Andrews every green crab was infected, often with every tissue and organ riddled with cysts which occurred sometimes singly and sometimes in clusters in the liver, gonads, and along the blood vessels, nerves and intestine. They noted, as had Lebour (1908), that the cysts varied in size, shape and thickness of wall. They measured cysts of three size groups; the small ones were oval with thin walls and the largest ones were spherical with thick walls composed of inner concentric and outer radial layers. Referring to the gradual increase in size of the cysts, the authors stated (p. 239), "From these figures there seems no reason to suppose that these groups are other than stages in the growth of the same cyst, and such being the case it is evident that the cercariae increase considerably in size during their sojourn in the crab." They measured a cyst from the original material of Prof. M'Intosh which was 0.29 mm. in diameter. They suggested a possible error in the measurement given in his (1865) report, mentioned also by Guyénot *et al.* (1925).

Lebour (1912) proposed that larval trematodes should be classified on bionomic grounds and arranged the British marine cercariae in two categories, dependent on whether they were produced in sporocysts or in rediae. Among those which develop in sporocysts, she gave a more complete account of *Cercaria ubiquita,* a larva which she previously (1907) had described from *Paludestrina stagnalis* at Fenham Flats and Loch Ryan on the west coast of Scotland. She reported that this species occurred also in *Littorina saxatilis* (syn. *L. rudis*), and at Millport the usual host was *Littorina obtusata.* The cercariae resembled *C. cellulosa* and *C. pusilla* of Looss (1896) and Lebour reported that they entered *C. maenas* and *Cancer pagurus* where they developed into "Spelotrema-like cercariae." The encysted larvae occupied (p. 432) "almost every tissue of the crab, liver, muscles, gonad and outside the blood vessels. Having settled down it grows considerably and the cyst with it, but the latter however is still very thin-walled. The stylet is lost when the cyst measures about 0.30 mm. across. The ventral sucker and alimentary canal appear and the body spines begin to form. The worm stops growing when the cyst is about 0.35 mm. across and then the cyst wall becomes very thick, 0.02 mm. thick, and the real resting stage begins. The cercaria is now of the ordinary *Spelotrema* form. The usual size of the thick-walled cyst is

0.4–0.48 mm. across." After describing the excysted metacercaria, Lebour stated (p. 433), "From what has been said there can be little doubt that *Cercaria ubiquita* is the young form of *S. excellens* the first host thus being *Paludestrina stagnalis, Littorina obtusata* and *L. rudis.* The intermediate host *Carcinus maenas* and *Cancer pagurus* and the final host probably the herring gull, *Larus argentatus.*" In this paper Lebour also gave figures of *Cercaria carcini* Lebour, 1908 and *Cercaria minor* sp. inq., both from *C. maenas.* These species were encysted and therefore metacercariae; furthermore, since the cyst walls were thin and the worms somewhat smaller, it is probable, as suggested by Nicoll and Small (1909), that these larvae are identical with the ones identified by Lebour as *Spelotrema excellens.*

Guyénot, Naville and Ponse (1925) described metacercariae which they found in a single, formalin-preserved specimen of *C. maenas* taken at Boulogne-sur-Mer, France. The cysts were oval, 0.40 by 0.35 mm., and the larvae were identified as *Spelotrema carcini* Lebour. These authors accepted Lebour's (1912) account, designating *C. ubiquita* as the larva of *S. excellens,* but noted that when computed from the stated magnification of the figure, the metacercaria portrayed by M'Intosh was only 0.13 by 0.16 mm. As noted earlier, M'Intosh gave no measurements and the presumed error in magnification may be explained by reduction in size of the drawing on publication. The French authors also described larger cysts, 0.90–1.2 mm. in diameter, in which the walls were weakened and the trematode larvae were filled with spores of a microsporidian, *Nosema* (*Plistophora*) *spelotremae* n. sp.

Stunkard (1932) described cercariae from *Littorina saxatilis* and *L. littorea* at Roscoff, France as *Cercaria ubiquitoides.* Although the larvae were very similar to *C. ubiquita,* slight differences between these specimens and Miss Lebour's description prevented their allocation to that species. In *C. ubiquita* Lebour described two ducts on each side, "which run up the body springing from two masses of large cells which occupy the greater part of the body." In her figure, Lebour showed six gland cells on each side with the two median ducts crossing to open on opposite sides of the body. The cercariae at Roscoff were described as having four penetration glands on each side of the body, with ducts which lead forward, three associated in a common bundle that passes along the lateral face of the oral sucker while the other duct lies more mediad and passes over the sucker. The penetration glands did not stain with neutral red but the secretory granules were clearly visible. These granules, colorless in the cell bodies, stained a deep blood-red in the terminal portions of the ducts and frequently accumulated there to form enlargements. Stunkard also described metacercariae from *C. maenas* and *Porcellana longicornis,* which were referred provisionally to the genus *Spelotrema,* but no attempt was made to relate them to *C. ubiquitoides.*

Rees (1936) described an ubiquitous cercaria from *L. rudis, L. obtusata* and *L. littorea* collected at Aberystwyth in February and March, 1935. He noted that the larvae were almost identical with those described by Stunkard (1932) from *L. rudis* and *L. littorea* at Roscoff. There were slight differences in measurement and other differences concerned the penetration glands, which in the specimens studied by Rees were, "more distinct, not lobed and the most anterior pair of cells is separated from the other three pairs." Rees declared (p. 621), "It is difficult to determine whether these differences are individual or specific because there are so few larval characters in cercariae of the Ubiquita group which can be used for separating species. The problem is rendered more difficult by the close resemblance of the adult trematodes (species of the genus *Spelotrema*)." In general, the measurements given by Rees agree with or overlap those given for *C. ubiquitoides,* except for the length of the stylet which measured 28 microns against "about 25 microns" in *C. ubiquitoides.* The size, shape and relative position of the gland cells are altered by degree of maturity of the larva, by contractions of the body musculature, and by the emission of secretion into their ducts. Since the ducts from the most anterior pair of penetration glands are separate from the ducts of the other cells, the cell bodies may be somewhat removed. The observation by Rees that only the two anterior pairs of cells and ducts take up neutral red stain, whereas the others do not, is a significant contribution to knowledge of the species. Obviously, I failed to note this feature in *C. ubiquitoides,* but the staining reaction differs with the constitution, concentration, age and condition of the neutral red solution. Accordingly, I am disposed to regard the larvae described by Rees and *C. ubiquitoides* as specifically identical. Since each penetration gland has its own duct, the account of Lebour is not precise and the lateral one of the two reported ducts on each side of the body is almost certainly a bundle of three ducts. Furthermore, it appears that *C. ubiquitoides* can not be distinguished from *C. ubiquita* Lebour, 1907, and the name should be suppressed as a synonym. Lewis (1926) had reported *Spelotrema simile* as very common in gulls of the Aberystwyth area and the finding was confirmed by Rees (1936) who stated (p. 624), "The unusually high percentage infestation of *Littorina rudis* with this cercaria, together with the high percentage of gulls parasitized by *Spelotrema simile,* suggests that this may be the larval form of this species."

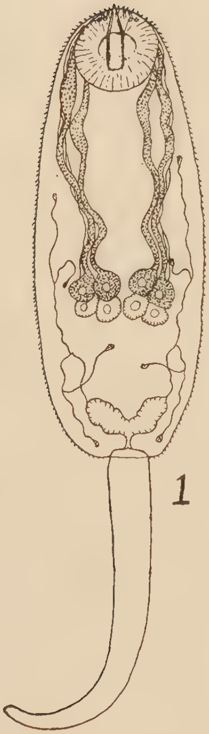
Cable and Hunninen (1938) described the successive stages in the life-cycle of a trematode which they identified as a new species, *Spelotrema nicolli.* The asexual generations were in the snail, *Bittium alternatum,* the metacercariae in the blue crab, *Callinectes sapidus,* and the sexual generation was developed in young herring gulls, *Larus argentatus.* These authors (1940) gave a more complete description of *S. nicolli,* the adult of which was compared with that of *S. pygmaeum, S. claviforme, S. simile, S. excellens* and *S. brevicaeca.* In size and size of organs, *S. nicolli* agrees closely with *S. simile;* the major difference is in the size of the male papilla, which is much smaller and similar to that of *S. pygmaeum.* The metacercariae were found only in certain slender fibers which extend from the viscera to the bases of the legs. Cysts increase from 0.05 to 0.50 mm. in diameter; the metacercariae become almost as large as the adults; the excretory formula is $2\ [\ (2+2)\ +\ (2+2)\ ]$, which persists in the adult stage. The cercaria agrees closely with the description of *C. ubiquitoides* and of the species described by Rees; the major difference is the shorter length of the stylet. *Spelotrema nicolli* is identified by the size of the male papilla, the location of the metacercariae, and the taxonomic position of the first and second intermediate hosts.

Timon-David (1949) reported metacercariae from the hepatopancreas of *C. maenas* in the Mediterranean at Marseille. The cysts were oval and on this feature and their size, they were identified as *Spelotrema carcini* Lebour.

The present report covers part of a project on clam investigation conducted by the U. S. Fish and Wildlife Service. Since the green or shore-crab, *C. maenas,* is a serious predator of *Mya arenaria* on the New England coast, a survey of its parasites was undertaken in an attempt to determine whether or not some of them might serve as possible means of biological control. It has long been known that *C. maenas* in the Woods Hole area is infected by an undetermined, encysted metacercaria and experiments have been conducted to discover its identity, life-history, and biology. Metacercariae were fed to white mice and excysted specimens (Fig. 6) recovered after 24 hours. Other cysts were fed to recently hatched, uninfected birds, *Sterna hirundo* and *Larus argentatus*. Large numbers of worms were recovered, including all stages from juvenile to fully mature specimens. The structure of the metacercariae, especially of the smaller and recently excysted ones, suggested that they may be specifically identical with a minute, stylet-bearing cercaria (Figs. 1, 1a) reported by Stunkard (1950), which occurs in *Littorina obtusata, L. saxatilis,* and rarely in *L. littorea*. Small green crabs were exposed to these cercariae and became heavily infected; enormous numbers of worms entered their tissues and developed to metacercariae, identical with those of natural infections. Small crabs exposed continuously with six to eight infected snails died in 10 to 20 days, and on dissection, each one yielded thousands of larvae. The parasites were present throughout the body of the crab, but the heaviest concentration was in the digestive gland. When first encysted, the cyst is oval, the wall is very thin, and the stylet persists for a long time. Eggs of the parasite, recovered from the droppings of terns and gulls, and others teased from the uteri of gravid worms, were used to infect specimens of *L. obtusata,* collected near the laboratory from an area which is not frequented by birds and where examination of 200 snails showed no infection. The eggs were embryonated under running sea water for seven days and then spread on fronds of *Fucus* which were allowed to partially dry to ensure that the eggs would become attached to the slimy surface of the alga. These fronds were placed with 10 small specimens of *L. obtusata* in a gallon jar with a small opening and sharply curved upper shoulders, half filled with sea water and provided with a stream of fine bubbles from an air pump. The water was not changed for ten days and subsequently on alternate days the top water was siphoned off and replaced with fresh sea water. Since the eggs of microphallid trematodes do not hatch until they are eaten by a suitable snail, and since from the design of the experiment it is impossible to tell when eggs were eaten, the age of an infection is not known precisely. The snails were first exposed on July 31, and on October 1, five snails that were alive in the jar were crushed and examined. Three of them were infected; two with large numbers of small daughter sporocysts but not yet producing cercariae, and the other contained three primary or mother sporocysts (Fig. 2) but no free daughters. The early stages of the infections afford clear evidence of their experimental nature and the complete life-cycle was thus consummated by laboratory infection of both intermediate and final hosts.

The adult worms agree so completely with the descriptions of *Microphallus similis* (syn. *Spelotrema simile*) as given by Jägerskiöld (1900) and Odhner (1905), that they are assigned to that species. The experimental demonstration of the life-cycle confirms the suggestion of Rees (1936), that *Cercaria ubiquita* Lebour is the cercarial stage of *M. similis*. Actually, the adults were described by Jägerskiöld (1900), the metacercariae by M'Intosh (1865), and the cercariae by Lebour (1907). Whether the specimens described by Nicoll (1907) as *S. excellens* and *S. feriatum* are specifically distinct remains to be determined.

Attempts to infect *Limulus polyphemus* were unsuccessful. Three small horse-



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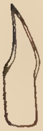

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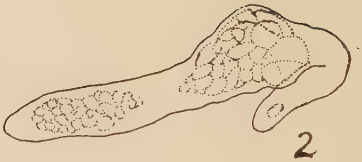

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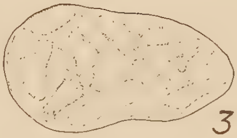

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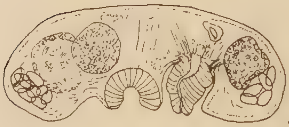

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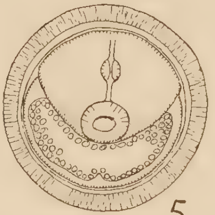

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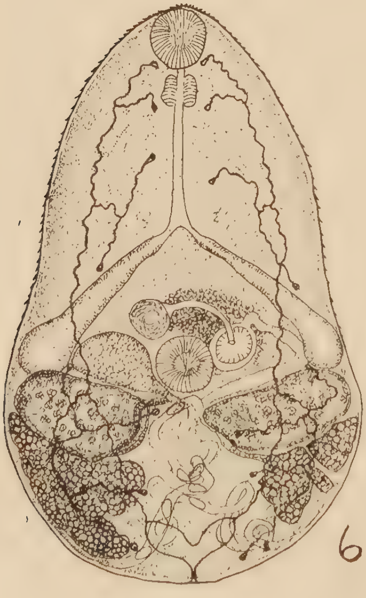

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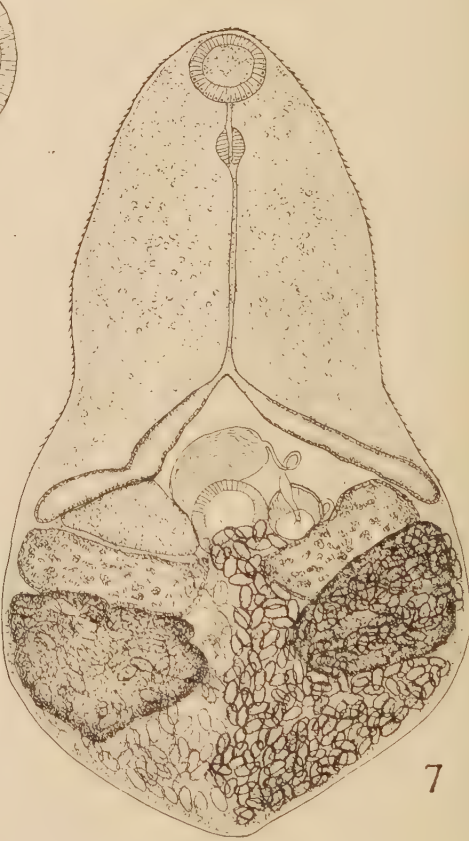

7

shoe crabs with carapace widths of 17, 19, and 21 mm., collected near Orleans, Massachusetts, were exposed to cercariae for two weeks. On dissection, there were no recently entered, unencysted larvae although all three harbored mature cysts of *Microphallus limuli* in their livers. This finding supplements that of Stunkard (1953), who reported full-sized cysts in small *L. polyphemus*. In paragraph 3, line 4, of that report, 3 mm. should read 30 mm.

Description of Stages in the Life-Cycle

Measurements in millimeters

Adults (Fig. 7)

Egg-bearing specimens from gulls and terns are about the same size. Fixed, stained and mounted they measured: length, 0.36–0.7; width, 0.22–0.36; acetabulum, 0.048–0.065; oral sucker, 0.05–0.065; pharynx, 0.02–0.03; male papilla, diameter 0.038–0.058; testes, 0.10 × 0.06 to 0.16 × 0.09; seminal vesicle, 0.06 × 0.04 to 0.09 × 0.064; ovary, 0.08 × 0.05 to 0.1 × 0.062; eggs colorless on the ovarian side, yellow on the antovarian side, 0.022–0.027 × 0.011–0.012, often collapsed and somewhat distorted in fixed and stained specimens.

The body is oval to pyriform and either end may be wider; often there is a slight constriction between the more mobile forebody and the inert hindbody which is filled with reproductive organs and eggs. The dermomuscular wall is thin and weakly developed; it consists of the usual circular, longitudinal and oblique layers, but the fibers are delicate and relatively few. The edges of the forebody tend to turn ventrad, forming an adhesive cup. The cuticula bears flattened spines which are conspicuous on the anterior half of the body but become smaller and sparser posteriorly. The suckers are approximately equal in size; either may appear larger, depending on the degree of contraction by the sphincter and the size of the orifice. The esophagus is long and when the body is extended, it may be much longer than the ceca. The ceca are almost straight; they diverge at an obtuse angle and terminate at the acetabular level. The anterior tips are constricted and lined with cuticula, continuous with that of the esophagus. The excretory system is unchanged from the metacercarial stage and has the formula $2[(2+2)+(2+2)]$. The testes are dorsal, lateral, opposite; the vasa deferentia arise at the medial, anterior faces, pass mediad and anteriad where they unite to form the seminal

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Figure 1. Cercaria from *L. obtusata*, free-hand drawing of specimen stained with Nile blue sulphate; 1a, lateral aspect of stylet.

Figure 2. Primary sporocyst from *L. obtusata*, experimental infection; fixed and stained specimen, length 0.30 mm.

Figure 3. Daughter or secondary sporocyst from *L. obtusata*; natural infection; fixed and stained specimen, length, 0.375 mm.

Figure 4. Cross-section of a mature worm to show the relative position and size of the acetabulum and of the male papilla. The metraterm opens into the genital atrium near the base of the papilla and in front of the left testis whose anterior portion appears in the section; width of the worm, 0.28 mm.

Figure 5. Metacercaria from *C. maenas*, natural infection; cyst 0.46 mm. in diameter.

Figure 6. Specimen, much flattened to study the excretory system, from intestine of a white mouse, 24 hours after the cyst was eaten; length 0.55 mm.

Figure 7. Adult specimen from intestine of *Sterna hirundo*, experimental infection; one of the largest specimens, flattened under a cover glass. fixed and stained, length 0.69 mm.

vesicle, an oval sac which lies anterior and dorsal to the acetabulum. A coiled ejaculatory duct, enclosed in glandular cells, leads from the vesicle to the muscular male papilla which almost fills the genital atrium, situated at the left of the acetabulum. The ovary is oval to triangular, located on the right side of the body, between the seminal vesicle and the testis and cecum of the right side. The oviduct arises from the median posterior region, coils posteriad and ventrad where it expands to form a fertilization space from which Laurer's canal winds to the dorsal surface of the body, opening in the midline just behind the acetabulum. The oviduct then turns dorsad and anteriad, receives a short common vitelline duct and enlarges to form the ootype, lined with cilia and enclosed in the cells of Mehlis' gland. The vitellaria are large, lobed glands, situated below and behind the testes; ducts from the two sides pass mediad, anteriad and dorsad, uniting to form the common vitelline duct which discharges into the initial portion of the ootype. The uterus passes backward from the ootype almost to the posterior end of the body and then loops forward in coils on the ovarian side of the body as far as the end of the digestive cecum, then backward almost to the posterior end of the body where it crosses to the opposite side and forms a corresponding series of loops on the left side, with the terminal metratermal portion emptying into the left side of the genital atrium (Fig. 4). The extent of the uterus anteriorly is determined by the number of eggs; in certain specimens the uterine coils may be below and behind the testes whereas in others the coils may underlie the ends of the digestive ceca.

The egg and miracidium

Egg-production begins almost immediately after the metacercaria is eaten by the final host. Figure 6 shows a worm which, fed as a metacercaria to a white mouse twenty-four hours earlier, already has eggs in the initial portion of the uterus. At first the egg-shell is thin, flexible and transparent; but as the eggs traverse the uterus, the shells become thicker, harder, and bright yellow. This coloration of the shell obscures the larva in living eggs, but development can be followed by study of serial sections of gravid worms. The egg is operculate and the ovum is situated toward the opercular end of the egg. In eggs near the metraterm, the miracidium appears to be fully formed, but eggs used for infection experiments were kept for a week in running sea water to insure fully mature larvae. The miracidia emerge only after the eggs have been ingested by the snail host.

Sporocyst generations (Figs. 2, 3)

The amount of experimental material is limited, but three primary sporocysts were removed from a specimen of *L. obtusata* two months after exposure to eggs of *M. similis*. These sporocysts were sluggish, oval to cylindrical and 0.25 to 0.40 mm. long. One of them, fixed and stained, is shown in Figure 2. The presence in them of recognizable daughters identified them as sporocysts of the mother or primary generation. Daughter sporocysts obtained from two experimental infections were young, small, and very numerous. Daughter sporocysts of natural infection measured 0.10 to 0.60 mm. in length; they are oval, occur in large numbers, more than one hundred in a single snail. The wall often contains a yellowish pigment; it is thin and in older sporocysts change of shape results from movement of contained cercariae. Figure 3 was made from a daughter sporocyst, 0.375 mm. long.

Cercaria (Figs. 1, 1a)

Body length, 0.1–0.22 mm.; width, 0.02–0.05 mm.; the larva is very thin, delicate, colorless. The tail is 0.01–0.012 mm. wide at the base; contracted it is 0.05 mm. long, with fine cuticular annulations; extended it may be 0.25 mm. long and very slender. There is no acetabulum; the larvae move by strokes of the tail but are unable to creep. They swim upward and sink when motionless. In swimming the body is contracted, bent ventrad, while the tail is extended and lashes violently. The body is covered with cuticular spines and the dorsal wall of the sucker bears a stylet, 0.023–0.026 mm. long and 0.009 mm. wide. The stylet (Fig. 1a) is asymmetrical in lateral aspect. The oral sucker measures 0.025–0.032 mm.; other parts of the digestive system are not yet developed. The body contains numerous cystogenous glands and on either side, near the middle, there are four penetration glands. The two anterior cells on each side differ from the posterior ones; the difference is demonstrated by the use of neutral red or Nile blue sulphate solutions, especially the latter, which stain the secretory granules of the anterior cells selectively while the contents of the posterior cells do not take the stain. Ducts from the anterior pair of cells pass forward beside those from the other cells for a short distance, but about halfway to the mouth they separate from the others and pass more mediad, crossing the dorsal side of the oral sucker, while the ducts from the other three penetration gland cells form a bundle that continues forward and passes at the side of the sucker. The ducts from the two anterior pairs of cells open to the surface ventrally, below the tip of the stylet, whereas the ducts from the posterior pairs open more anteriorly and at the sides of the tip of the stylet. The excretory system is shown in Figure 1; the vesicle is U- or V-shaped and the flame-cell formula is $2[(1+1)+(1+1)]$. The cercariae are carried by respiratory currents into the gill chambers of *C. maenas* where they enter the body at the bases of the gills and possibly at other non-cuticularized places, pass by way of the vascular system to all parts of the body, and localize principally in the connective tissue of the digestive gland.

Metacercaria (Fig. 5)

The cysts increase in size and measure from 0.05 to 0.55 mm. in diameter; when the cercariae encyst they are bent ventrally; the cyst is oval and the wall is very thin and flexible. The stylet is retained for some time and readily identifies the species. As the metacercaria grows, the digestive tract and actabulum are formed and the number of flame-cells is doubled. As the worm grows, the cyst becomes spherical and the wall increases in thickness. In a full grown cyst, the cavity may be 0.35–0.40 mm. in diameter and the wall consists of two layers, an inner hyaline one which may be resolved into strata and attains a thickness of 0.02 mm., and an outer radially striated layer which increases to a thickness of 0.06 mm. The substance of this layer, after digestion in a pancreatin solution, appears to consist of parallel prisms. The worms become almost full grown as metacercariae; the adults increase in size only by the further activity of the reproductive organs and the accumulation of eggs in the uterus. When younger and smaller metacercariae are eaten, the worms become gravid at a smaller size than when the metacercariae are older. The excretory vesicle of older metacercariae contains spherical concretions, the excretory wastes accumulated during the period of encystment.

SUMMARY

1. The life-history of *Microphallus similis* has been worked out by experimental infection of both intermediate and final hosts.

2. Encysted metacercariae from *Carcinides maenas* developed to sexual maturity in *Larus argentatus* and *Sterna hirundo*. Eggs of the parasite developed in these hosts were used to infect *Littorina obtusata*. Two generations of sporocysts were recovered.

3. *Littorina saxatilis* and *Littorina littorea* also harbor the asexual generations at Woods Hole, Massachusetts.

4. The cercariae are minute, stylet-bearing monostomes and small green crabs, *C. maenas,* exposed to these cercariae became heavily infected; enormous numbers of larvae entered the tissues and developed into metacercariae identical with those of natural infections. Small crabs, each exposed continuously to the cercariae from six to eight infected snails, died in ten to twenty days and on dissection each yielded thousands of larvae.

5. The stages in the life-cycle of the parasite agree with descriptions by European investigators of corresponding stages: the metacercariae with metacercariae from *C. maenas,* described but not named by M'Intosh (1865); the adults with *M. similis* from Swedish gulls, described and named by Jägerskiöld (1900); and the cercariae with *Cercaria ubiquita* Lebour, 1907. The identity of these parasites as stages in the life-cycle of a single species is predicated.

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Commercial fishermen depend on supplies of shrimp, menhaden, trout, and other fishes which utilize the inner bays and shallow waters for spawning and early life stages.

hould areas be set aside as Fish Nursery Grounds

By PAUL E. THOMPSON

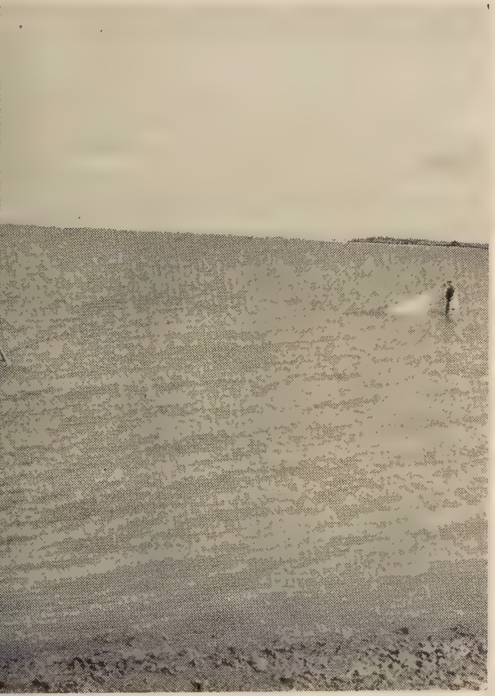
U. S. Fish and Wildlife Service

THERE may be someone somewhere willing to come before the Gulf States Marine Fisheries Commission and recommend without further consideration that fish sanctuaries be established by State law in Apalachicola Bay, Mobile Bay, Mississippi Sound, Lake Pontchartrain, and Laguna Madre. I am not so brave, so I have re-phrased the question so that it might be expressed as *"what do we know or need to know in order to decide whether nursery grounds should be set aside?"*

The appeal of the refuge or sanctuary or nursery ground is undeniable. "Refuge" and "sanctuary" connote security; "nursery ground" has a pleasant connotation with a childhood surrounded by affection and protection and security. The question here is whether we can, by setting aside certain inshore waters as sanctuaries, provide security for our fishery resources, reduce their death rates, and thus increase the numbers growing to catchable size each year.

We have lost or nearly lost several species of fish and wildlife. The passenger pigeon and the bison are the classic examples, but the whooping crane, trumpeter swan and Atlantic salmon are about as good. Many wildlife experts agree that extinction or near extinction has resulted from reduction in the environment of animals having rather narrow tolerance limits and only limited adaptability. Just two weeks ago the North American Wildlife Conference decried the destruction of over half the country's wetlands through drainage for agriculture and flood control. That destruction reduces the waterfowl environment and thus the natural production of waterfowl.

There is no question that sanctuaries are desirable and useful for animals whose environment would be or is being destroyed by civilization. Evidence for waterfowl refuges, strategically located along the flyways, is overwhelmingly favorable. Wildlife conservationists can view the situation now with a measure of complacency as compared with the situation twenty years ago.



g samples from the inner bays and shallow waters
e valuable information about the movement and
eding habits of game and commercial fishes.

There is no lack of thrills and excitement on a wild coon hunt.

Mountain Music

By GORDON K. SHEARER

WILD COON HUNTING, a sport that has gained w popularity in Texas, has a number of surprising f tures. Most other hunting is for the purpose of a k Carrying a gun on a wild coon hunt is forbidden. I dog kills a coon on the hunt, the dog is disqualified.

In fact, wild coon hunting is one sport of which it tru can be said that the criterion is how the game is playe

Because of this sportsmanship and the affection man for a fine dog, wild coon hunting is becoming a major o door activity in nearly every state.

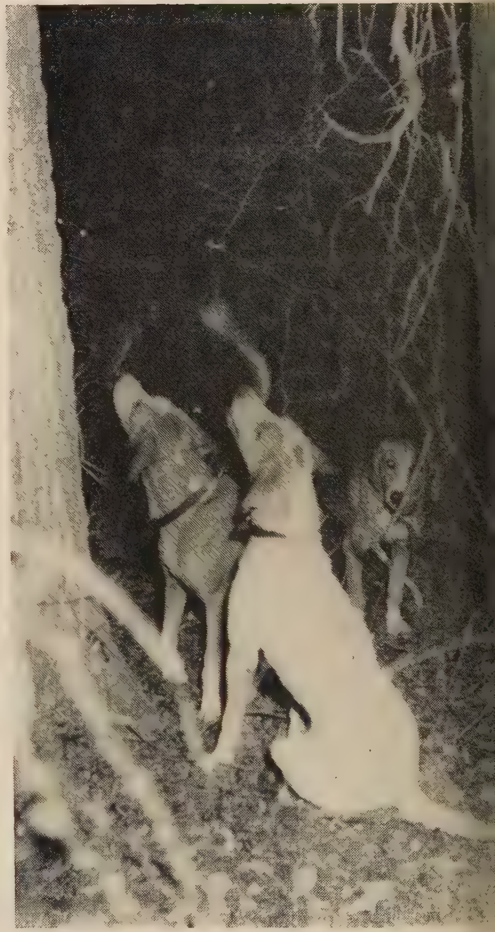
For two successive years the National Mountain Mu Wild Coon Hunt has been held in Texas. Both times was at Fort Parker State Park which is between Groesbeck and Mexia. Coon dog field trials were scheduled this year at San Augustine, Mexia, Jacksonville, Winnsboro, Tyler, Grand Saline, Waco, and Galveston. These field trials began in February and will continue through December. Bench shows for coon dogs also are held, usually in connection with a hunt or field trials. Field trial awards are for "line" and for "tree." "Line" is passage through a fixed location. Hunts are scored on the dogs entire performance.

The 1957 National Mountain Music Wild Coon Hunt at Fort Parker had 150 dogs entered by owners who came from 12 states to the park on the Navasota River for three nights of coon hunting. Many of the owners brought along the whole family. One party included the dog owner, his wife, four children and a maid.

The first impression received by a novice visitor to a wild coon hunt is that he has wandered into a canine Babel. As the tenderfoots ears become attuned, he begins to distinguish the melding sounds. By nightfall when the casts are made and the hounds pick up the trail, he knows without asking why the name Mountain Music is appropriate.

It is uncanny how, despite darkness and distance, a dog owner or handler can "read" what a dog is doing. Scoring begins when a dog sounds that he has struck the trail of a coon. From the sound, the owner or handler knows and notifies the judge that it is his dog that has struck. The first strike counts a hundred points. The scoring continues

○ *Continued on page 27*



Dogs receive points for being the first to strike the trail of a coon and for treeing. An owner can recognize the "voice" of his dog and notifies the judge when his dog has struck.

t can we apply the same principles to our fisheries? t there be a red herring here? Is there the possi- of our being over-influenced by emotional ap- And might we be lulled into a sense of false se- y with our fish refuges that, in the long run, would us worse off than now? These are questions I ld like to examine with you.

hanks to biologists like Gunter, Collier, Lindner, erson, Pearson, Viosca and others and their work the past 25 years we know a good deal about the ore waters of the Gulf. As one result of their work, ave awakened to the truly tremendous importance he coastal environment for most of the valuable es, even many of those usually regarded as offshore

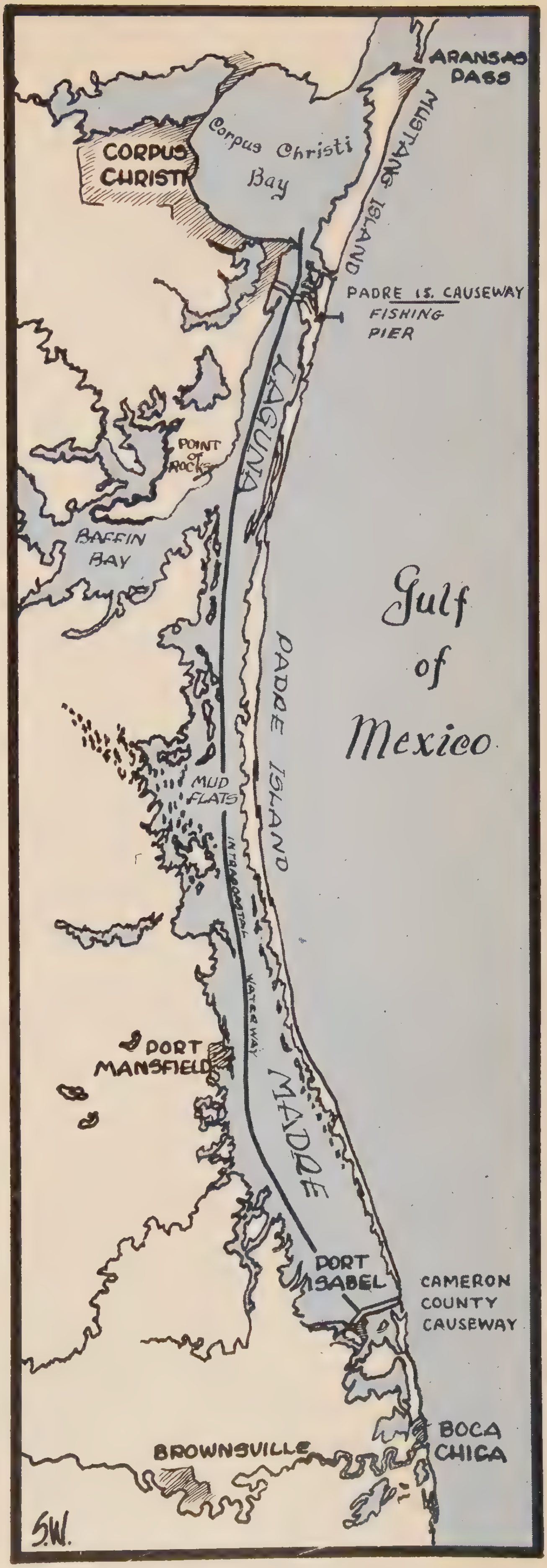
e know that shrimp, menhaden, redfish, black n, sea trout, croakers, spot, striped bass, mullet, k—all are absolutely dependent upon the inshore s, the inner bays, the shallow waters for spawning arly life stages, or both. So we know that the richly luctive inshore waters must be preserved or even roved if we are to take the best crop for sport or merce year after year.

here are forces along the Gulf coast working at an lerated pace in these prosperous times to reduce the ability or actual surface acreage of these inshore ers. Domestic, industrial and agricultural pollution ncreasing with population growth, industrialization he South, and wide use of potent insecticides and bicides. Real estate developments in several areas changing the ecological conditions and shrinking total environment. Channel dredging, drainage, filling to make new land are re-arranging the face he Gulf coast and shifting such physical features as er currents and silt deposition. Diversion of stream s and diking sections of coastal bays can change perature and salinity regimes and current patterns.

n the other hand, there are natural forces involved vell. Workers in Texas tell us that the productive una Madre with its shallows, lack of permanent inage, high evaporation rate, and poor connection n the Gulf proper, periodically undergoes natural erse changes in salinity. Then young fish in this e nursery ground are killed by the thousands. In ations of this kind and in others it may be possible, n more knowledge, to devise ways of maintaining d conditions for fish survival, or even to improve ditions. In other situations, where conflicts between production and civilization arise, it may be possi- to minimize potential damage at the very least.

do not know of any generalization about the pro- tivity of inshore Gulf waters in terms of pounds of produced per surface acre. I do know of freshwater ds having produced at the rate of two and one-half s of fish per surface acre per year. From statistics of

• Continued on page 31

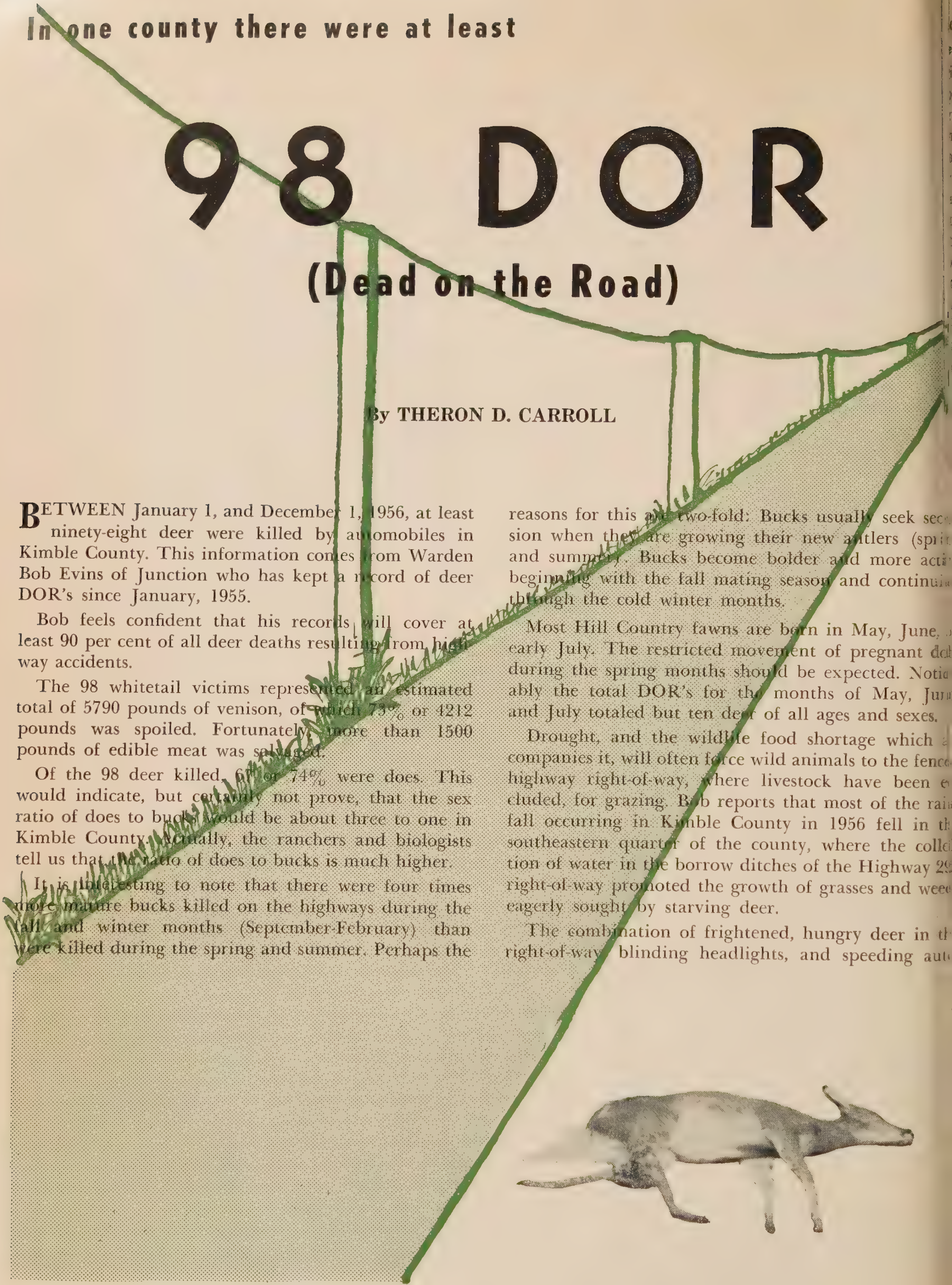


Preservation and improvement of waters such as those of the Laguna Madre and adjoining inshore waters is necessary to insure the best crop of marine fishes for sport and commercial fishing.

In one county there were at least

98 DOR

(Dead on the Road)



By THERON D. CARROLL

BETWEEN January 1, and December 1, 1956, at least ninety-eight deer were killed by automobiles in Kimble County. This information comes from Warden Bob Evins of Junction who has kept a record of deer DOR's since January, 1955.

Bob feels confident that his records will cover at least 90 per cent of all deer deaths resulting from highway accidents.

The 98 whitetail victims represented an estimated total of 5790 pounds of venison, of which 73% or 4212 pounds was spoiled. Fortunately, more than 1500 pounds of edible meat was salvaged.

Of the 98 deer killed, 6[illegible] or 74% were does. This would indicate, but certainly not prove, that the sex ratio of does to bucks would be about three to one in Kimble County. Actually, the ranchers and biologists tell us that the ratio of does to bucks is much higher.

It is interesting to note that there were four times more mature bucks killed on the highways during the fall and winter months (September-February) than were killed during the spring and summer. Perhaps the reasons for this are two-fold: Bucks usually seek sec
sion when they are growing their new antlers (spri
and summer). Bucks become bolder and more acti
beginning with the fall mating season and continu
through the cold winter months.

Most Hill Country fawns are born in May, June,
early July. The restricted movement of pregnant do
during the spring months should be expected. Notic
ably the total DOR's for the months of May, Ju
and July totaled but ten deer of all ages and sexes.

Drought, and the wildlife food shortage which
companies it, will often force wild animals to the fenc
highway right-of-way, where livestock have been e
cluded, for grazing. Bob reports that most of the rai
fall occurring in Kimble County in 1956 fell in th
southeastern quarter of the county, where the colle
tion of water in the borrow ditches of the Highway 2
right-of-way promoted the growth of grasses and wee
eagerly sought by starving deer.

The combination of frightened, hungry deer in th
right-of-way, blinding headlights, and speeding au

uld nursery grounds be set aside?

Nursery Grounds——— * Continued from page 11

ıp and menhaden catches and uction of other species and limited information on the fe- ity of these, we can safely as- a high productivity potential he Gulf waters. Will a fish sanc- here and there along the coast ect, perpetuate or enhance this uctivity and allow us to relax assume we have solved the prob- of protecting the young?

good many observers, some here his meeting, have reported vast ols of post-larval and young off- ng of Gulf spawners entering the passes and bays of the western and northern Gulf. They know from their collections that the young fish spread throughout the shallow, inner waters where they feed and grow rapidly. Some species, like the speckled sea trout, spawn in inside waters and their young move still farther into the shallows for the early part of their life.

The fish aren't going to know about the refuges established for them. They will continue to move freely throughout the bays and inside waters which they find agreeable. Selection of a few thousand acres by each State and setting them aside and patrolling them to keep out poachers is not going to be enough.

A better possibility, I think, than the refuge or sanctuary idea, is the "setting aside," if you want to call it that, of all of the Gulf coast nursery grounds, such that the State fishery agencies have clear authority to control or to prohibit actions immediately detrimental or cumulatively detrimental to the quality of the inshore environment essential to the well being of their fishery resources. Facing the facts of life suggests that there will be no inviolate sanctuaries, and I think none of us would want them. What we do want and need is legislative appreciation of the importance of the nursery grounds to the economy and well-being of the Gulf coast and of the nation and statutory recognition of the necessity for keeping them productive.

If such authority is conferred by State legislatures, there will be a coordinate responsibility given the conservation agencies. That is to seek all the knowledge necessary to judge the effects of proposed changes in the environment on the creatures living in it; to seek the knowledge necessary to improve the habitat where natural conditions cause excessive mortalities; and then to offer positive, practical methods of minimizing bad effects of encroaching civilization.

In other words, greatly stepped-up research effort will be necessary over the coming years, and this will be expensive in terms of money and men. Men will continue to be hard to find for several years, but they can be found. Money could be made available for research from licenses, and this could include fees from salt-water anglers.

More authority and more research are my suggested substitutes for refuges or sanctuaries for protection of fishery nursery grounds. **

on-resident Fishing License Fees ary for Texas and Nearby States

great number of vacationists e to Texas each year to enjoy excellent fishing afforded by as' many lakes and rivers. Pos- Kingdom Lake, for example, is ous nationally as one of the ma- fishing lakes. And not many es can boast better fishing than Texas coast, for both surf and water anglers.

Iany people are thinking in terms fishing, not only in Texas but in other southwestern states. -resident fishing licenses are re- red in Louisiana, Arkansas, Okla- ıa, Colorado, New Mexico, Ari- a, and Texas. In each state the uirements vary. For example, the imum age at which a fishing nse is required, and special areas in which additional fees or special regulations are in effect are not the same for all states. It is best to check with the game warden, fishing license dealer, or Game Commission in the state in which you plan to fish and vacation for special regulations which may pertain to you. A knowledge of these special laws and regulations can add measureably to your vacation fun.

Whether you stay in Texas or take advantage of the many fishing opportunities offered, or take an out-of-state vacation, be sure to observe the fishing laws of the state you are in, and obtain the license you need.

Wherever you go . . . GOOD FISHING!

Non-resident Fishing License Fees

	Louisiana*	Arkansas	Oklahoma	Colorado	New Mexico	Arizona**	Texas
al non-resident fishing license	$5.	$5.	$5.	$10.	$8.	**	$5.25
non-resident fishing license				3.50	3.	**5.	1.65
non-resident fishing license	2.						
y non-resident fishing license		2.	2.25				

ouisiana requires a license for all resident fishing, both fresh and water.

Arizona: There are a number of ial laws pertaining to specific ers in Arizona. Check the Arizona ing Regulations for additional in- ation before buying one of these ng licenses:

Non-resident warm water	$ 5.00
Non-resident warm water (5-day)	3.00
Non-resident Trout	10.00
Non-resident combined fishing (5-day)	5.00
Non-resident Colorado River fishing	5.00
Alien General Fishing	25.00

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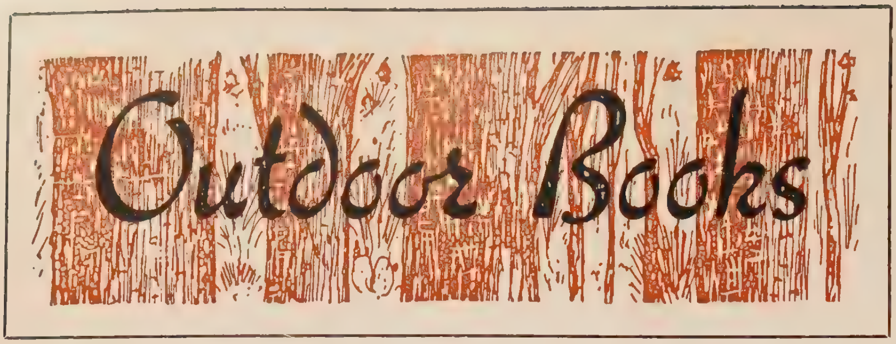

Outdoor Books

THE FUTURE OF ARID LANDS edited by Gilbert F. White. Papers and recommendations from the International Arid Lands Meetings. 464 pages with graphs, diagrams and black and white photographs. Published 1956 by the American Association for the Advancement of Science, 1515 Massachusetts Avenue, N.W., Washington 5, D.C. $5.75.

In April and May of 1955 a group of scientists took part in the International Arid Lands Meetings in New Mexico for an exchange of thinking on arid lands research problems. Scientists from 17 countries were present at the meetings where various papers, including "Using Arid Lands Beyond Capabilities," "Agricultural Use of Water Under Saline Conditions," and "Induced Precipitation" were presented. This book is a compilation of these papers.

The program centered upon those areas of investigation where prediction of the future currently must be based upon insufficient understanding and data. One of the widest fields for research is the concept of selecting, breeding and improving plants and animals for arid conditions, rather than adapting the land to the animals. Another point which was repeatedly emphasized was the importance of translating scientific findings into action at the level of the farmers, herders and landowners.

Although the papers from the meetings and the recommendations of the conference are printed in this book, the more important outcomes will continue to show themselves in years to come through the work of individual scientists acting on suggestions developed from these papers.—J.R.

COTTONTAIL RABBIT by Elizabeth and Charles Schwartz. 44 pages gaily illustrated with numerous color drawings. Published 1957 by Holiday House, 8 West 13th Street, New York 11, New York. $2.50.

The cottontail rabbit, an animal of interest to all children, is found throughout the United States, even in city vacant lots. One of the most preyed-upon mammals, its ability to run and hide is its only defense.

The authors have written this book with an understanding of the cottontail, without deviating from scientific fact. The book is gaily illustrated, and easy to read.

The adventures of a cottontail for one year are presented. It feeds, plays, mates, makes nests, bears young, nurses them, and eludes its enemies. A personalized tone is used, making the animal seem realistic.

Explanation is given in the text of the rabbit's importance in the food chain of life. A child can understand through the experiences of the rabbit that death and survival are part of nature's pattern.—D.W.

SHOOTING'S FUN FOR EVERYONE. Eighteen page, two-color illustrated booklet published 1957 Sporting Arms and Ammunition Manufacturers' Institute, 250 East 43rd Street, New York 17, N York. Free upon request.

The why, where, when, and how of rifle shooting for boys and girls is answered in this attractive and readable booklet, recently released by the Sportsmen's Service Bureau.

Designed for young readers, the booklet presents helpful word and line sketches on the history of marksmanship in America. It tells youngsters how shooting clubs can be organized and where information and assistance can be obtained. Fundamental firing position, rifle tournaments and game hunting tips, and rifle selection are discussed. Information on assorted shooting safety reminders and firearms is given throughout the text.

Copies of "Shooting's Fun for Everyone" may be obtained from the publisher.—D.W.

THE AMERICAN SOUTHWEST by Natt N. Dodge and Herbert Zim. 156 pages generously illustrated in color by Arch and Miriam Hurford. Published 1955 by Simon and Shuster, Inc., Rockefeller Center, New York 20, N. Y.

For anyone who plans to visit the great Southwest, this book is an excellent reference guide. It is unique in giving the tourist not only an overview of points of geographic and historic interest, but essential information about the people and characteristic land forms, plants, and animals.

The authors suggest itineraries and offer a wealth of information (with maps) on national and state parks, Indian reservations, old forts, ghost towns, and Spanish missions.

This entertaining book is filled with colorful, accurate paintings. The information is complete, detailed, and well organized, with a rich diversity of interest that will delight tourists and armchair travelers alike.—D.W.

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ULTRASONIC TRACER Follows Tagged Fish

By PARKER S. TREFETHEN,
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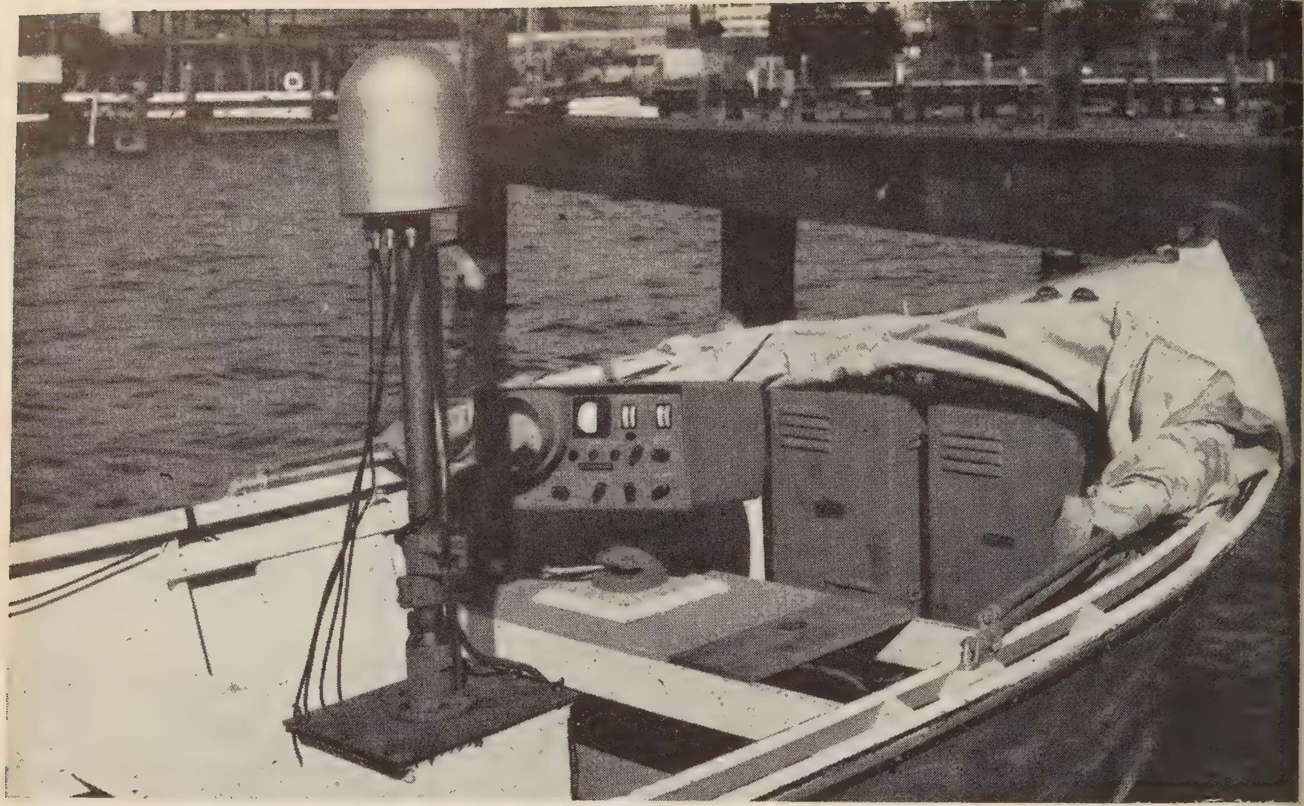


FRONT COVER: Field installation of automatic ultrasonic tracking and ranging system on U. S. Fish and Wildlife Service boat Wendy. Five-transducer array is on servo-driven rotating and tilting mount inside dome. Ultrasonic signals (132 kc for tracking and 270 kc for ranging) travel through air to water. Equipment can also be used for studying crabs and lobsters

ULTRASONIC TRACER

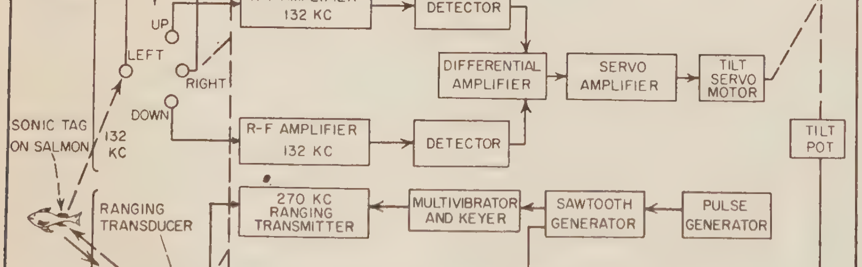
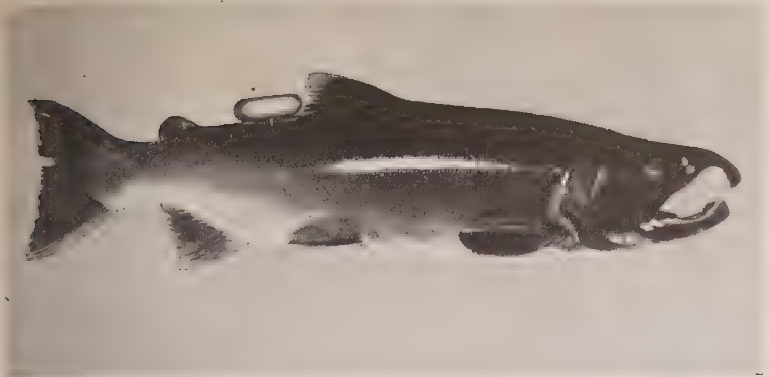


FIG. 1—Complete automatic tracking and ranging system for tagged fish

DEVELOPMENT of automatic ultrasonic tracking and ranging equipment for the Fish and Wildlife Service provides a method for obtaining information on adult salmon behavior in relation to dams in the Northwest. The design and production of this new research tool was prompted by the need for obtaining a more detailed knowledge of individual salmon behavior than has been possible by conventional methods.

The equipment consists of a miniature ultrasonic source (sonic fish tag), a self-positioning directional transducer array with a receiver-servo system (auto-track) and an echo-ranging system arranged as in Fig. 1.

In operation, the tracking system positions itself or homes on the sonic tag attached to a fish and aims the transducer in that direction. The range and bearing of the fish are displayed on a calibrated cathode-ray tube. The depth of the



Sonic tag on silver salmon has carefully adjusted buoyancy so as not to affect natural movements of fish. Pulse repetition rate of transistor oscillator in tag is adjustable; with appropriate receiver tuning facilities, up to ten different fish can be tracked simultaneously

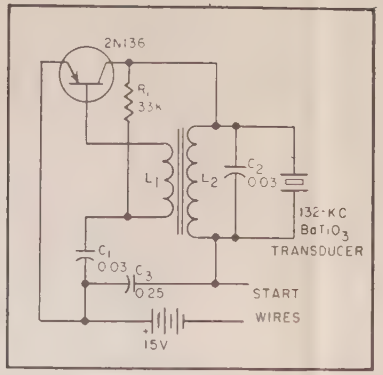


FIG. 2—Pulsed 132-kc ultrasonic oscillator used in sonic fish tag can be detected at distances up to 2,000 feet

SUMMARY —— Single-transistor pulsed ultrasonic oscillator with 7-hour battery life is clipped to adult salmon on spawning run. After fish is released, movement is tracked with sonar-type equipment on boat to obtain detailed fish behavior patterns in relation to dams. Servo-controlled four-transducer receiving array tracks tagged fish automatically to give elevation and azimuth. Sonar ranging transducer in center of array is thus aimed directly at fish

Follows Tagged Fish

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Senior Engineer *Senior Staff Engineer*
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fish is calculated from the range and the angle at which the ultrasonic impulses from the equipment are projected into the water. By plotting the position of the fish and the position of the boat simultaneously, the operator is able to obtain detailed fish behavior patterns.

Ultrasonic Fish Tag

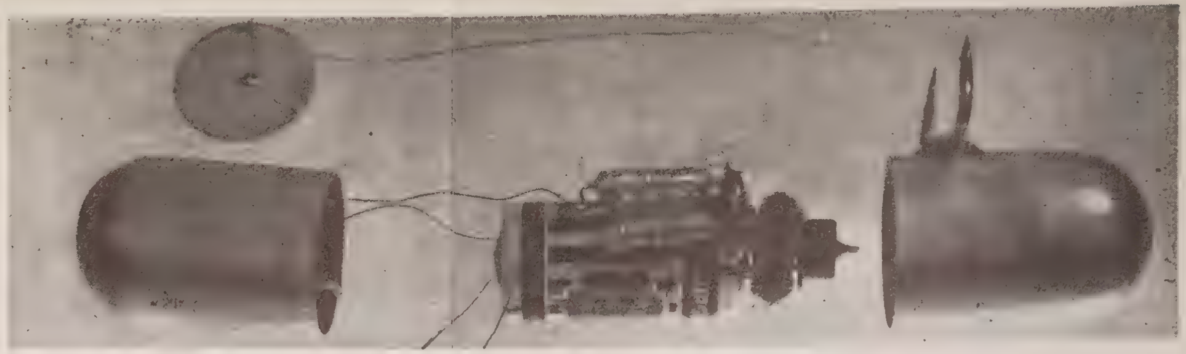
To permit attachment to relatively small fish with minimum modification of their behavior, the sonic tag must be of miniature size. Opposed to this requirement is the need for battery life of 8 to 12 hours. Accordingly, circuitry in the sonic tag was chosen to hold current requirements to a minimum.

The additional requirement of approximately neutral buoyancy modifies the package to some extent. The resultant capsule is 2⅜ inches long, 0.9 inch in diameter, weighs 29 grams in air and displaces 27 grams of fresh water.

The capsule shell, spun from 7-mil aluminum, is provided with a soldered-on hog ring for attachment to the fish. The tag closes with a slip fit and is sealed with vacuum grease, a wrap of plastic tape and an over-all plastic dip to ensure water tightness to a depth of 30 feet.

Economy of battery life is improved by pulse operation of the sound source. The common-emitter transistor oscillator circuit used in the sonic tag is shown in Fig. 2. Here R_1 and C_1 establish an interruption rate of 2,000 pps and a pulse length of 200 microseconds. The values of L_2 and C_2 and the clamped capacitance of the transducer determine the 132-kc operating frequency.

The transducer used in the sonic tag is a barium titanate disk 0.040 inch thick and 0.86 inch in diameter. The disk is one-half wavelength in diameter, resonant in the radial mode at 132 kc. It has silver fired on both surfaces and small lead wires soldered to the nodal point or center of each side. The transducer mounts inside one end of the spun aluminum capsule, at the break point of the end radius. Epoxy resin cement secures it in place and gives acoustic coupling to the aluminum shell. This construction, which provides a marked benefit in matching the acoustic impedance of the disk to the water load, gives the desirable nearly circular radiation pattern shown in Fig. 3.



Contents of ultrasonic fish tag. Crystal transducer (top) fits into left half of capsule, which is shaped and dipped in waterproofing plastic solution after assembly. Two leads at lower left come out of capsule through joint, for connecting together to complete circuit just before fish is released. Smaller tag is now being developed for use on small fish

With this circuit arrangement an r-f voltage of 25 volts peak-to-peak is developed across the transducer, providing a signal level of 5 microvolts at the receiver grid at 400 feet. The 15-gram 15-volt battery has a useful life of 7 hours at a current drain of 3 ma.

Automatic Tracking System

The servo-powered automatic tracking system uses four receiving transducers, each connected to one of the four receiving channels. Two of these transducers are used for azimuth tracking and two for elevation tracking. Each azimuth transducer has a beam pattern with a response 10-db down at 20 degrees from its axis. The transducers are mounted with an angle of 40 degrees between their axes. A sound source on the bisecting axis of a pair will produce in each a signal which is 10-db below its maximum response. If this source is moved from the bisecting or common axis toward either transducer axis, the output from that transducer will rapidly increase towards its maximum while the output from the other will decrease. If the two signals are used to balance each other in a difference amplifier, the resultant sharply defined null provides excellent sensitivity to small angular displacements from the common axis.

The receivers use a high-gain trf circuit with a bandpass of ±4 kc to the 3-db-down point. Two of the tracking receiver channels and their common servo amplifier are shown in Fig. 4. Each channel has a biased triode (V_{5A} and V_{10A}) operating as a detector, feeding the 2,000-cps repetition rate frequency of the sonic tag to a zero-bias amplifier. The audio signals from the two channels are rectified by 1N38 diodes which are directly coupled to the grids of the cathode-follower difference amplifier. The output signal from the difference amplifier is a bidirectional d-c voltage which is then modulated by a 60-cps chopper. The chopped signal is amplified by a 60-db amplifier which drives an 8-watt 2-phase servo motor geared to the transducer clus-

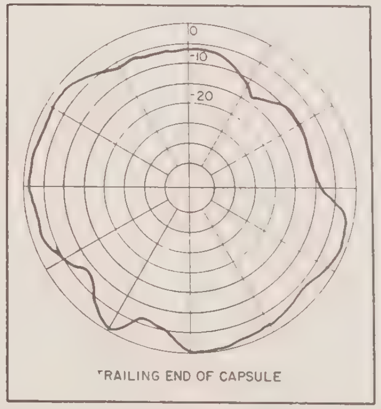


FIG. 3—Ultrasonic energy distribution pattern in horizontal plane for tag attached to fish

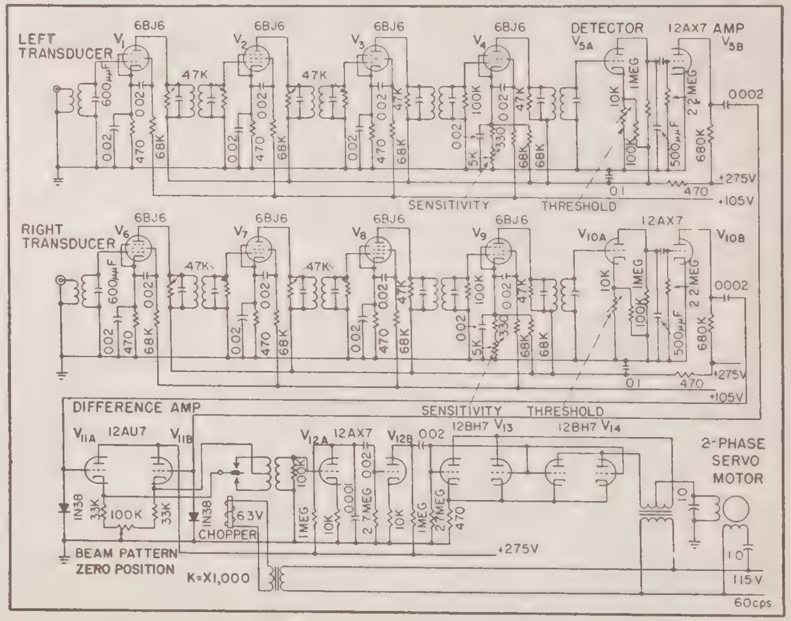


FIG. 4—Azimuth tracking receiver channels, servo amplifier and motor circuit for horizontal rotation of transducer array

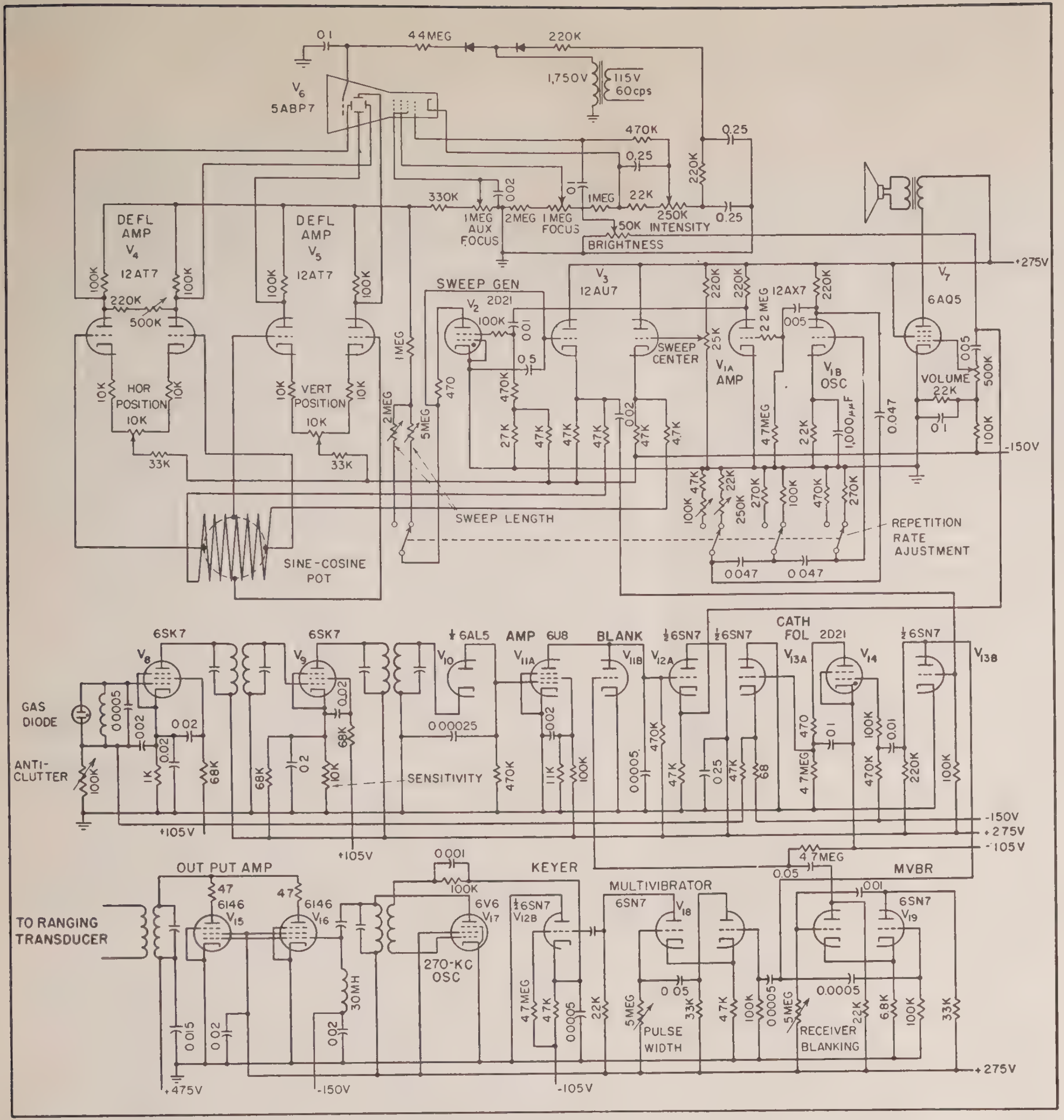


FIG. 5—Transmitter-receiver and indicator display circuits of echo ranging system

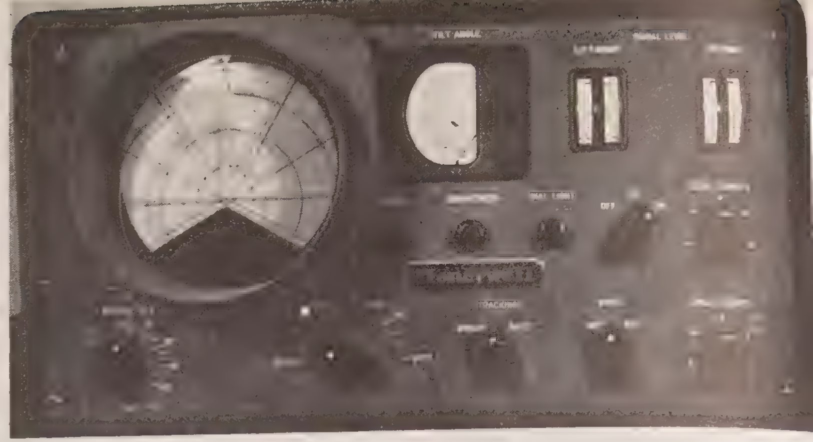
ter. Directional sensitivity is inherent in the phase sensitivity of the servo system.

Information on angular position of the sonic tag is presented to the operator as azimuth information and elevation angle (always negative). Azimuth angle is displayed on a ppi scope in conjunction with range information. This is accomplished by using the range sweep sawtooth signal as an input to a sine-cosine potentiometer which is rotated with the azimuth axis, as indicated in Fig. 5. The sine-cosine potentiometer output is amplified by four triode deflection amplifiers to provide a radial sweep for the cathode-ray tube, in synchronism with the transducer cluster azimuth angle. A conventional potentiometer is coupled to the elevation axis to transmit elevation data to a panel meter.

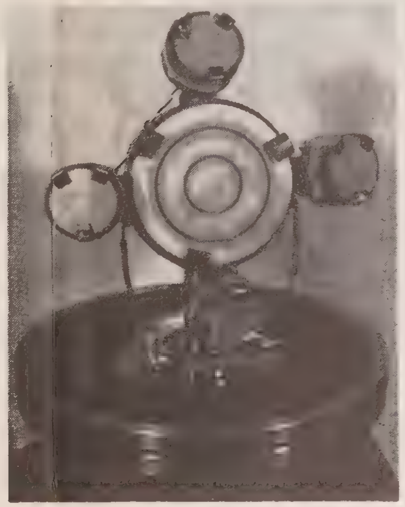
The ranging system may be described as an echo-ranging searchlight sonar system. A short pulse of ultrasonic energy is emitted by a direction transducer. The transmitted pulse encountering a target results in a small portion of the energy being reflected and returned to the receiving transducer as an echo. The transit time is then a measure of range.

In the ranging circuit of Fig. 5, a pulse repetition rate of 6 cps (400-foot range) or 3 cps (800-foot range) is generated by phase-shift oscillator V_{1B} and is shaped in saturation amplifier V_{1A}. The differentiated leading edge of this pulse triggers sawtooth sweep generator tube V_{2}. The sharp leading edge of the sawtooth is used for timing and synchronizing all time-dependent functions.

In the major signal path this synchronizing signal triggers monostable multivibrator V_{18} which determines the transmitted pulse width of 500 microseconds. This in turn, acting through keyer tube V_{12B}, keys on 270-kc oscillator V_{17} and output amplifier V_{15} and V_{16}. The type 6146 transmitter output tube was selected for high pulse output at relatively low voltages. The transmitted acoustic pressure is 120 db above 1 microbar at 1 yard from the ranging transducer.



Operator's display panel on boat. Bright spot of light appears on ppi screen, behin calibrated scale on which bearing and range of fish can be read directly. Tilt-angl meter at right of scope gives angle at which beam of ultrasonic impulses enters wate when aimed at fish. Depth can be calculated from range and angle



Transducer cluster with protective cover and coupling fluid removed. Ranging transducer is in center of cluster of four tracking units

Special pliers permit attaching tag in 30 seconds to back of fish behind dorsal fin, without handling fish in 4-foot-square underwater trap

A single transducer serves for transmitting the outgoing pulse and receiving the returning echo. Coupling is by means of a three-winding transformer with a gas-discharge tube across the receiver winding to decouple the receiver during the transmitted pulse. The transducer in the ranging system is 3.25 inches in diameter with a 5-degree major beam angle at 6-db down. Signal-to-noise ratio and forward sensitivity are greatly enhanced by this directional characteristic. The ranging receiver uses a trf circuit and is conventional through the r-f amplifier and diode detector. The output of the detector is a negative-going pulse and is direct-coupled through amplifier V_{11A} to cathode follower V_{12A}, then directly to the c-r tube control grid for the desired Z-axis intensity-modulated display. An audio signal is picked off at this same point to present an audible sound of the echo pulse.

Minor signal paths are used to perform auxiliary functions. The synchronizing leading edge of the sawtooth is also used to actuate blanking monostable multivibrator V_{19}. The multivibrator produces a pulse slightly longer than the transmitted pulse, applied to receiver blanking tube V_{11B} to effectively blank out the receiver during the transmitted pulse. This eliminates a high-intensity center spot from the ppi and suppresses the transmitted signal in the audio channel.

Time-varied gain in the receive
is controlled in a cyclic manner b
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2D21 thyratron V_{14} develops th
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and cathode follower V_{13A} couple
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The operator can, to a degre
modify the amplitude of this gai
control sawtooth. A panel kno
labeled CLOSE TARGETS provide
him with controlled discriminatio
against close-in target response. I
addition to this, he has a main r
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SMALL TARGETS.

Applications

Utilization of the newly deve
oped equipment reveals the b
havior patterns of adult salmon
fishway entrances, fishway exit
near spillways and near powe
house sections of dams.

Although originally designed
study salmon behavior, the equi
ment is not limited to specific pro
lems in fishery research. When
is employed at sea, detailed i
formation can be added to the pre
ent knowledge of tuna, albaco
whale and many other fish.

Thanks are due to the Seat
Development Laboratory, Ordnan
Division, Minneapolis-Honeyw
Regulator Co., designers and man
facturers of this device, for pe
mission to release this article.

Reprinted from THE JOURNAL OF PARASITOLOGY, April, 1957,
Vol. 43, No. 2, page 205.

NEW HOST AND LOCALITY RECORD FOR *TRIAENOPHORUS CRASSUS* FOREL (*CESTODA: PSEUDOPHYLLIDEA*)

The adult form of *Triaenophorus crassus* Forel, 1868 (= *T. robustus* Olsson, 1893; = *T. tricuspidatus* morpha *megadentatus* Wardle, 1932) occurs as an intestinal parasite in the pike, *Esox lucius* L., a holarctic species of wide distribution. Preliminary life-history stages include procercoid development in copepods of the genus *Cyclops* followed by plerocercoid development in the musculature of a variety of coregonid and salmonid fishes. The unsightly appearance of even moderate plerocercoid infections is often sufficient to render fish unacceptable for human consumption. In the prairie provinces of Canada the incidence and intensity of *T. crassus* infections in the commercially important whitefishes constitute a serious economic problem.

During an extensive survey of parasites of chum salmon, *Oncorhynchus keta* (Walbaum), we were supplied with small samples of marine-caught adults taken in August, 1955 and in July, 1956 in a gill-net fishery conducted near Kotzebue, Alaska (66° 56′ N–162° 30′ W). One of 12 salmon in the 1955 sample harbored 3 plerocercoids of *T. crassus* in the epaxial musculature. Among 10 fish in the 1956 sample, 4 were similarly infected with 1, 2, 6, and 15 plerocercoids respectively. Inquiry among Kotzebue fishermen by C. Fiscus, Fish and Wildlife Service biologist, revealed that the parasite is well known to them and appears in approximately 10% of the chum salmon catches from year to year.

The occurrence of *T. crassus* in chum salmon is unusual in that this species of salmon ordinarily spawns but a short distance from the sea. Newly hatched juveniles usually remain in fresh water only for the short period required for absorption of the yolk sac whereupon they descend to the sea, with little or no interim feeding activity, for a maturation period of 4 to 6 years. Mature chum salmon entering the Kotzebue Sound area eventually spawn in the Kobuk and Noatak river systems, each of which has extensive pike populations. It is evident from the rate of *T. crassus* infection in these chum salmon that significant numbers of juveniles must linger and feed in the rivers for sustained periods of time. The relatively common occurrence of the parasite in such an atypical intermediate host suggests an even higher incidence in suitable non-anadromous hosts indigenous to the area.

The foregoing account constitutes the northwesternmost record of *T. crassus* in North America. Proximate records include the Wood River Lakes system in southwestern Alaska, approximately 550 miles to the south; the Teslin Lake region, approximately 950 miles southeast on the northern British Columbia border; and Great Bear Lake, Northwest Territories, some 1100 miles to the east. The present locality record, well within the boundaries of the late Siberian-Alaskan land bridge, lends considerable support to the hypothesis of Lawler and Scott (1954, J. Fish. Res. Bd. Canada **11**: 884–893) that *T. crassus* entered North America with *Esox* via that route.—J. R. UZMANN AND M. N. HESSELHOLT, *U. S. Fish and Wildlife Service, Seattle, Washington.*

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Audio in Salmon Research*

A Fish Detection System at Bonneville Dam

Richard H. vanHaagen

U. S. Fish and Wildlife Service, Seattle, Washington

A master-oscillator multiple-detector system for following the movement of adult salmon through a series of underwater orifices is described. The fact that fish exhibit greater conductivity than fresh water has been known for many years, but this is the first known application to American fisheries instrumentation.

A sinusoidal audio-frequency oscillator supplies individual conductivity bridges; the unbalance due to fish passage, amplified, operates a relay; the make-break differential of the relay supplies an annunciator action, appropriately switching lights at a central control rack, showing the biologist the orifices chosen by each fish. Reset of the detector advances an electromechanical register.

INTRODUCTION

ISHERIES biologists of the Fish and Wildlife Service, instrumenting the Fisheries Engineering Research Facil- at North Bonneville, Washington, required a system ich would permit the detection of migratory fish passage ough experimental orifices of various sizes in the facility hways. The extremes of turbidity there render visual thods impossible.

Preliminary requests were for a lock-in or annunciator pe of indication, with manual reset. Sensitivity was to such as to indicate passage of small salmon through an fice at least 21 in. square in a weir 8 in. thick.

ENVIRONMENT

The facility is housed in a substantial temporary building ig. 1), 216 ft long and 36 ft wide, covering a watertight ugh, 16 ft deep and 24 ft wide; the trough is an un- errupted 100 ft long. In addition, there is a 40-ft pool each end. The upstream flow-introduction pool is floored h a wood grating 1 ft lower than the flume floor. The wnstream collecting pool is 7 ft deeper than the flume.

A traveling crane and removable partitions allow various angements of experimental fish ladders in the flume; ter flow and lighting are controllable, the latter by high-ensity mercury-vapor floodlamps in the windowless lding.

Migratory fish are bypassed through the building by rance and exit fishways connected to the regular Washington shore fishladder, which surrounds three sides of the building. Water is obtained from the forebay of the dam. Turbidity (Secchi disc scale) ranges from 5 ft to less than 0.1 ft, rendering visual observation uncertain.

Flux linkage from overhead distribution lines causes appreciable power levels in all conductors in the area, but experience has shown that the running of instrumentation wiring through metallic conduit or expanded metal raceways, plus care in design of equipment to avoid "ground loops," or multiple common returns, has allowed operation of all electronic instrumentation so far attempted. Preliminary noise-level measurements with electrodes in the water have indicated much lower levels there, perhaps due to the high resistivity of the water (around 10,000 ohms per cm^3).

Preliminary Investigations

It has been demonstrated both in Great Britain[1] and the United States that the conductivity of fish in fresh water is greater than that of their environment, and that this difference is sufficient to make it possible to upset a balanced Wheatstone bridge, one leg of which contains a water path through which the fish may pass.

Investigations for this facility were made using a bridge-balance method, with one leg of the bridge consisting of the water path between two parallel strip electrodes mounted

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* Presented at the Eighth Annual Convention of the Audio Engi- ring Society, New York, September 26–29, 1956.

[1] Lethlean, N. G., "An Investigation into the Design and Performance of Electric Fish Screens and an Electric Fish Counter." *Transactions of the Royal Society of Edinburgh,* 62, Part II (No. 13) 479–526. Twenty-five figures, 2 plates.

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1956, v4, 151-158

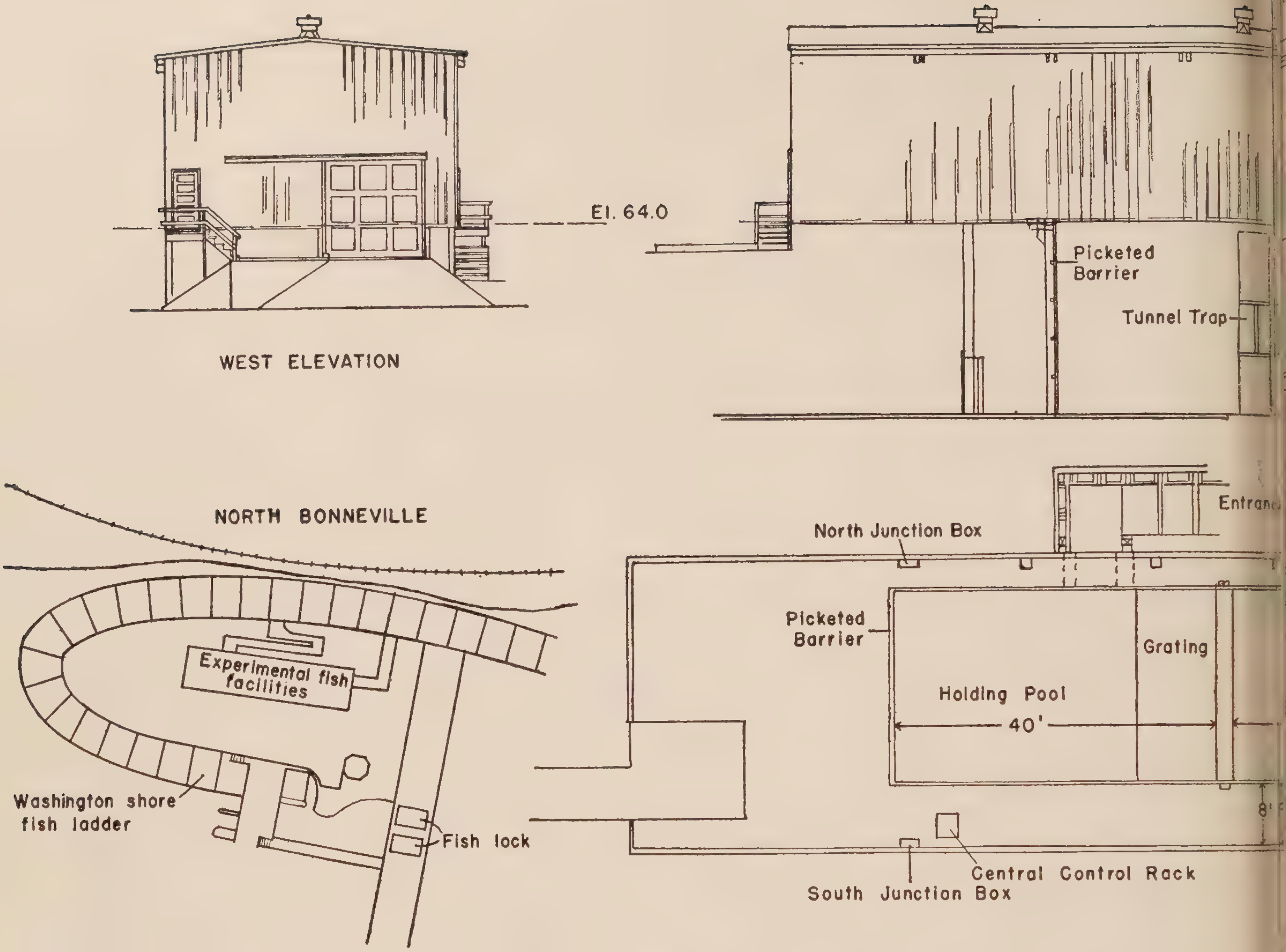


FIG. 1. Fisheries-Engineering Research Facility.

opposing each other across an orifice. The balancing of the bridge was accomplished by manual adjustment of an adjacent resistive leg. The orifice in the 8-in. thick test weir was 21 in. square and is shown in Fig. 2.

The plywood weir and its sill were covered with polyester resin reinforced with glass fiber. Several coats of silver conductive paint, allowed to dry thoroughly between coats, formed the electrodes, one of which was placed on the face of the weir along the edge of the orifice. The other electrode was on an axis parallel but on a plane normal to the first, on the 16-in. sill which closed the bottom of the orifice. An attempt was made to avoid difficulties which might result from the changing of electrode contact areas by entrained air. Three widths of electrode were used: ½ in., 1 in., and 1½ in., successively exposed by stripping a covering of vinyl electrical tape.

The secondary of the transformer feeding the bridge formed two legs of the bridge. The center tap was one of the bridge output terminals. The common point between the balance leg and the water leg was used as the other output

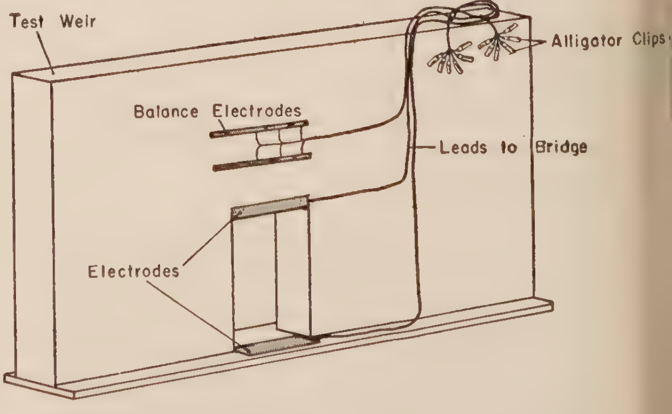
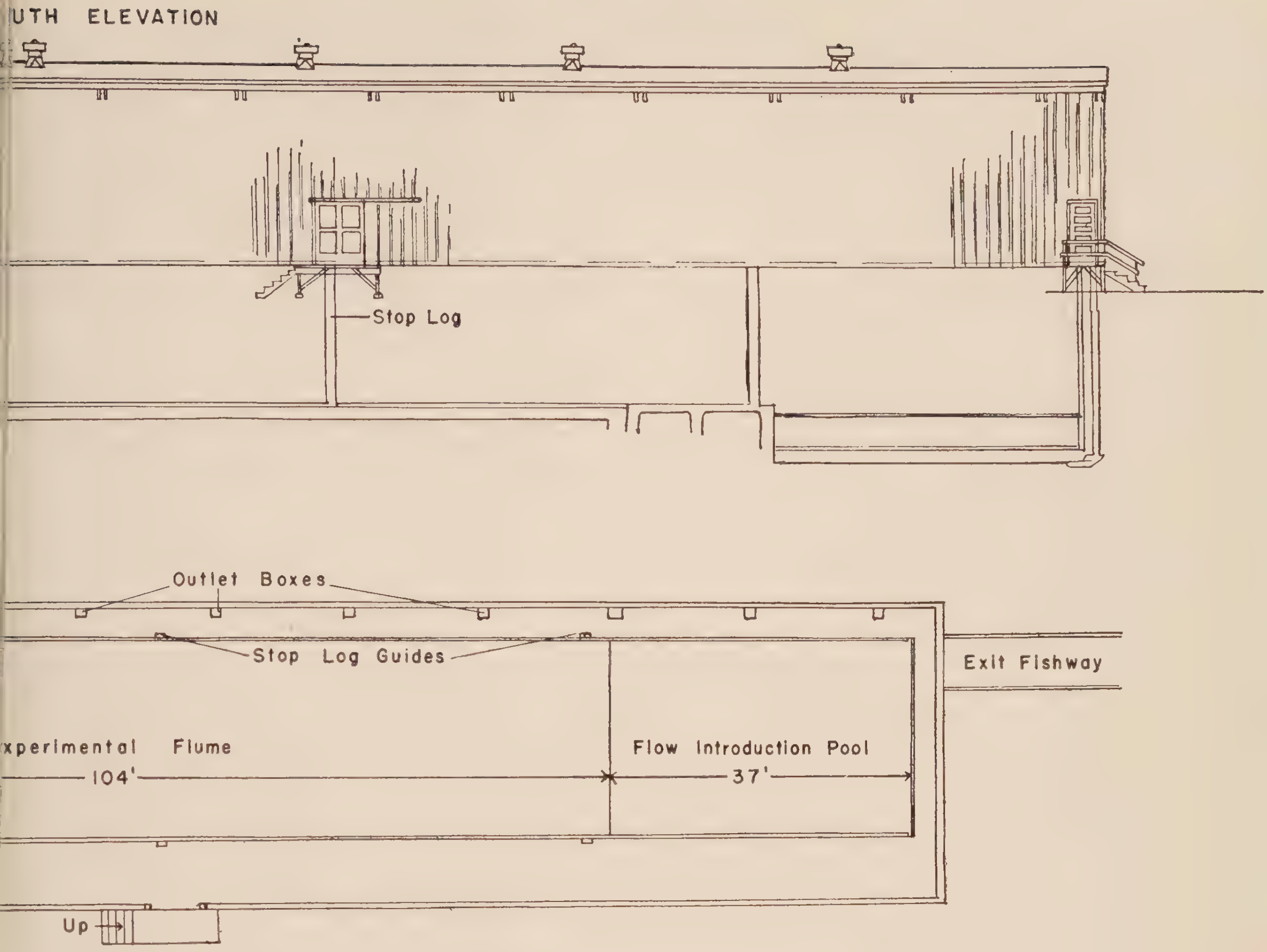


FIG. 2. Eight-inch test weir with 21-in. square orifice.



inal. Measurements of unbalance were made on a vlett-Packard 400-D vacuum-tube voltmeter, and the lge was supplied from a motor-alternator and Variac; voltage applied to the electrodes—half of the secondary voltage—was 0.25 to 25 volts rms, at 480 cps, as shown in the block diagram of Fig. 3.

Signal voltages due to fish passage were in the millivolt range, as were the residual unbalance and noise voltages, with a signal-to-noise ratio of 2:1 (for large fish) down to less than unity for small fish.

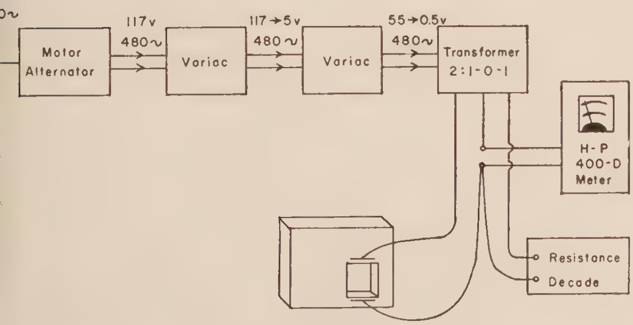


Fig. 3. Block diagram, preliminary investigations.

SYSTEM DEVELOPMENT

Since an annunciator action on the part of the detector was desired, any signal above the peak noise level would be adequate; since the noise level was quite constant and uniform in the water, and freedom from power-supply transients was guaranteed, engineering of the system could proceed with some security. The principle to be used was as follows:

The unbalance signal and background noise could be amplified to a level sufficient to operate a relay. The gain could be reduced so that such threshold would be attained only by passage of a fish of a certain desired size or larger. The relay would have a differential between pull-in and drop-out exceeding that of the power change caused by the fish, and the relay would lock in. Instantaneous low-resistance shunting of the relay coil would allow it to drop out.

This shunting would be accomplished manually, and could be accompanied simultaneously by operation of an electromagnetic register, tabulating the event. A pattern of registers would simulate a pattern of orifices, and the count recorded would indicate the passage of fish, which were to be released one at a time in early experiments.

The greatest restriction on the system was budgetary. Also, shop and staff facilities were quite meagre and the final design for the detector uncertain. A combination of locally designed units, for the bridge and relay circuitry, and a Heathkit amplifier for power amplification seemed optimum under the circumstances.

Since 10 or 15, and later more, detectors must be operated, a central variable-frequency oscillator and power amplifier, also Heathkit, were included. By using the detectors' "bass cut" and "treble cut" controls at their extremes, a bandpass characteristic could be obtained which would improve the signal-to-noise ratio over that experienced during the preliminary investigations, and the oscillator could then be "tuned" to the point of the detectors' greatest sensitivity—about 600 cps.

It was decided to locate the central control rack, containing the registers, reset buttons, indicator lamps, master oscillator, amplifier, and detector power switches at the west end of the building, near the flow valves, alongside the holding pool. Outlets for connecting detectors would then be spaced along the length of the fishway on the north wall. Provision was made for later use of a second frequency, if fields from two adjacent orifices interacted. Bandpass characteristics of the detector amplifiers would then be adjusted suitably, one using a high audio frequency, above 5 kc perhaps, and the other, or others, operating at a relatively low frequency.

DETECTOR DESIGN

The detector (Figs. 4a and 4b), is contained in a box fabricated from two chassis hinged with piano hinge and fastened with suitcase catches. Power (117 volts ac, 60 cps), bridge audio input (9 volts ac, approximately 600 cps), and output connectors are grouped on the bottom. The unit is designed to hang from the "barn door" handle.

One-half of a bottom plate mounted on the front chassis contains operating records, schematics, and spare cables.

The bridge transformer and the resistance balance leg are contained in the box in the lower right.

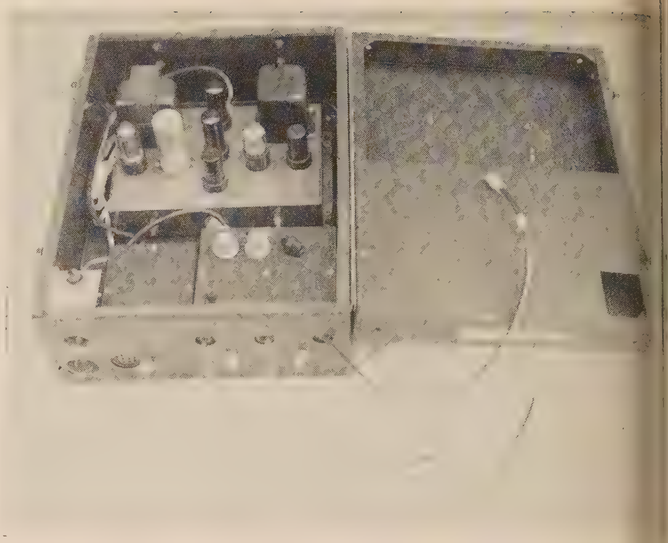


Fig. 4a. Detector. The box is made of two chassis hinged wit piano hinge and fastened with suitcase catches.

The box at the left contains a matching transforme diode bridge rectifier, and a sensitive relay. By makin these two units self-contained, it was felt that better control of noise sources could be obtained, circuit design could be altered more easily, and therefore money could be saved. in practice, servicing has been easier, in addition.

The bridge transformer is a center-tapped 6.3-volt ac filament transformer operating from the 9-volt ac line. Connections to the electrodes are made directly by mean of RG 59/U cable with UG 260/U connectors.

As designed and used, the center cable and either of th two outer cables are joined; the remaining cable is ther connected to the electrode pair and balancing accomplished manually. The balance resistors consist of five 180-ohm, 2-watt resistors mounted in series on a tap switch at the right, plus a 200-ohm rheostat in the center, a 20-ohm rheostat at the left, and a fuse, all in series.

While it is possible to use two similar orifices, balanced in the same ratio as the center tap of the transformer, this has not been realizable; the balance resistances, mounted on the cover of the box, must be shunted across one or the other of the two orifices, by using a *T* connector and the center cable, which has a UG 261/U connector.

For balancing two orifices, substitution of a 10-turn potentiometer for the balance resistors, with amplifier input taken from the arm instead of the transformer center tap, has proven satisfactory. Phase balance also improves the null.

Upon completion of the prototype of the detector, a test was made of the sensitivity of the circuit as constructed. An orifice 18 in. high and 6 ft long in a 2-in. thick weir, with electrodes painted on the upper and lower faces, op-

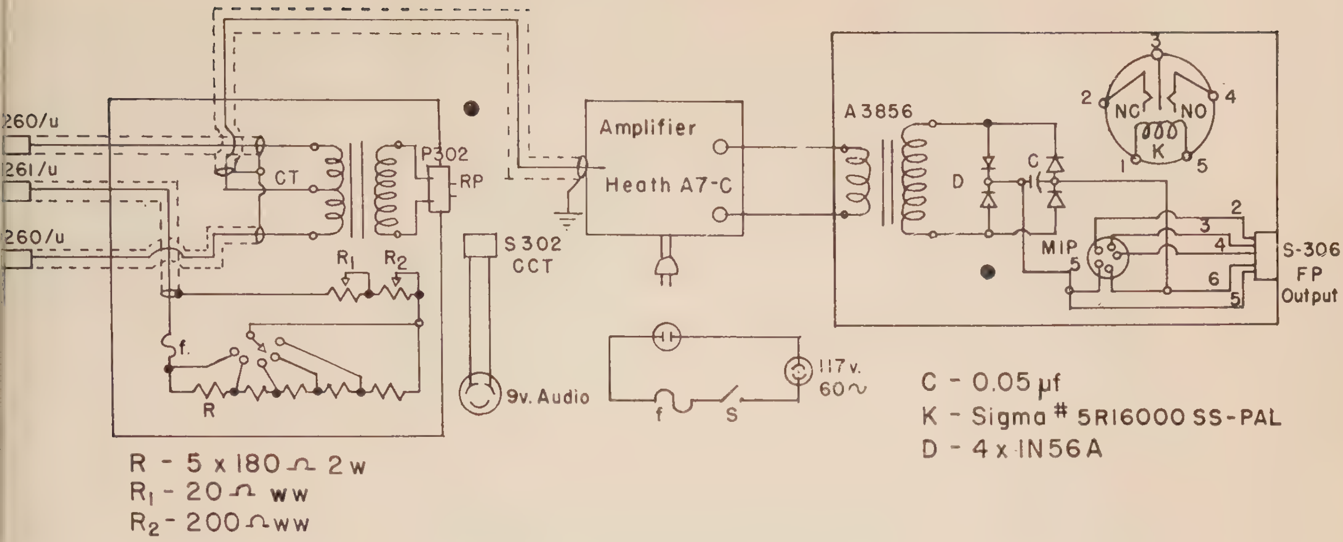


FIG. 4b. Detector schematic.

ing each other, was fastened in the facility fishway and ı passed through. Sensitivity was such that passage of amprey eel approximately 1 in. in diameter and 18 in. g was detectable (i.e., tripped the relay). All salnids passed were detected at reduced sensitivity. Subse-ent production units have been equally sensitive.

Each detector cost approximately 70 dollars for parts by il order and was assembled at a labor cost of 42 dollars.

Hand-Held Annunciator

Balance of the bridge is simplified by use of the handld annunciator unit, which is shown in Figs. 5 and 6. voltmeter, a 0-200 microamp meter with a 2-stage multi-er, is shunted across the relay coil by plugging the 6-pin nnector into the output-connector socket. A tenfold in-ease in meter sensitivity is obtained by depressing the red tton, which decreases the multiplier resistance.

The meter indicates the voltage across the relay coil, and nce is a measure of the bridge's balance. In operation amplifier gain is raised until roughly midscale reading the meter is obtained. The balance resistors are then justed, from right to left, in such a direction as to cause ower reading, and the gain again increased. The process repeated until the left-hand rheostat causes an increase signal when turned in either direction.

The sharpness of the null is a measure of the noise level the bridge, and if a broad null is found, disconnection the audio input indicates whether the poor null is due a residual unbalance or other causes. A major offender found to be coupling through the amplifier's power transmer to the 60-cps 117-volt ac line; reversal of the plug ove and behind the power switch and fuse bracket often minates this as a source of difficulty.

To put the detector into operation, the bridge is balanced as described, and the gain increased until the lamp in the hand-held annunciator is lit. The adjacent black button is then intermittently depressed, shunting the relay coil. The gain is decreased until the lamp remains *out;* any increase in input signal or gain will then light the lamp.

The lamp is supplied by 2 mercury cells which should be replaced every 2 years. Ordinary "penlite" cells may be used.

During extended use of the meter without regard to relay operation, the lamp may be removed from the outside by first unscrewing the clear plastic dome which covers it, thus conserving battery life.

Rack-Mounted Annunciators

Five recording annunciators are mounted side by side across the rack as one unit (Fig. 7). Each of the 3 units

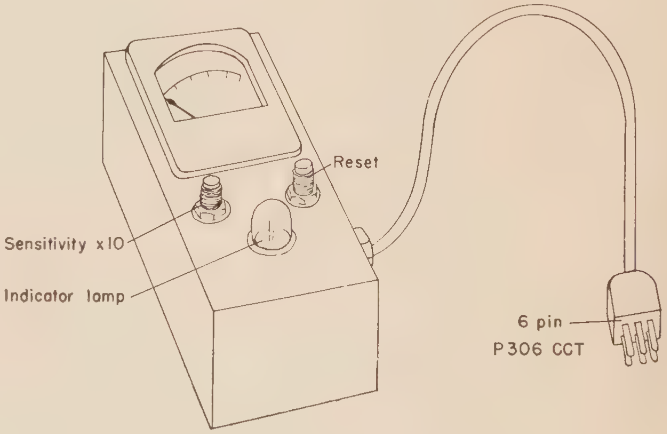


FIG. 5. Hand-held annunciator.

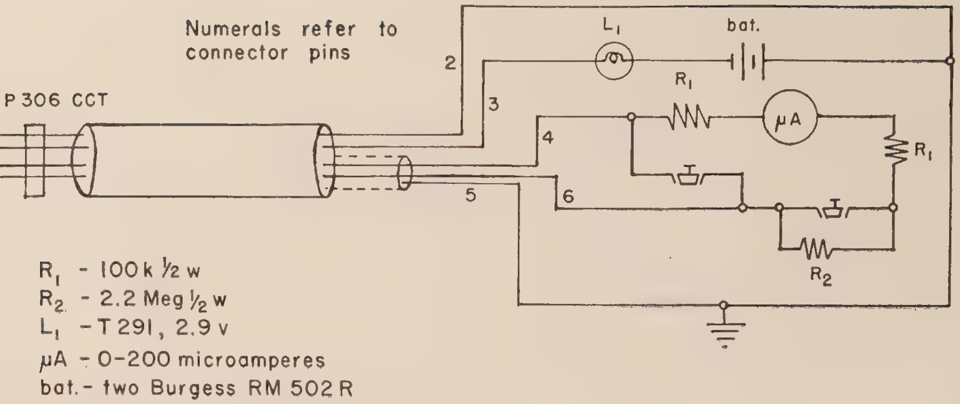
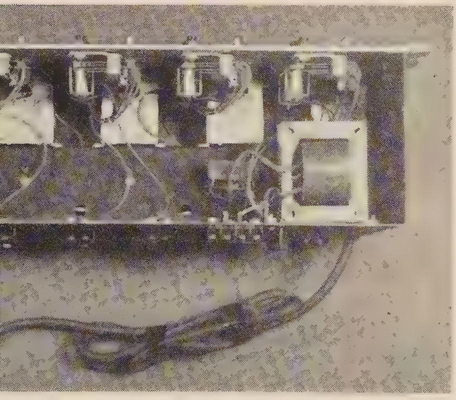


FIG. 6. Schematic of the hand-held annunciator.

wer source (a transformer) for the 10
. The circuit is shown in Fig. 8. After
balanced and put into operating condi-



-mounted annunciator, bottom view.

ove, the drop cord from the outlet box
ce of the hand-held annunciator. The
np on the rack-mounted annuncitaor will

light, indicating the *"ready"* state.

Detection of a fish passage will energize the relay in the detector and change connections so as to cause the relay at the rack-mounted annunciator to operate. This lights the red lamp, indicating an unbalanced detector. Depressing the button marked *"reset"* will shunt the detector relay coil, restoring the green lamp, and will also complete the circuit for operation of the adjacent register, so that a count is recorded. This latter function obtains only when the register switch is in the *"local"* position; in the *automatic* condition human control will be obviated, but this circuitry has not, at the present writing, been installed. No count is recorded when the switch is in the *off* position. A bell, mounted in the rack at the top, announces each detection.

OUTLET BOXES

Ten outlet boxes (Fig. 9) were mounted along the north wall of the building, connected to the raceway by 2-in. conduit. Each box is equipped to supply 3 detectors. Sockets are of the "twist-lock" type, the larger socket supplying the audio-frequency bridge input current, and the

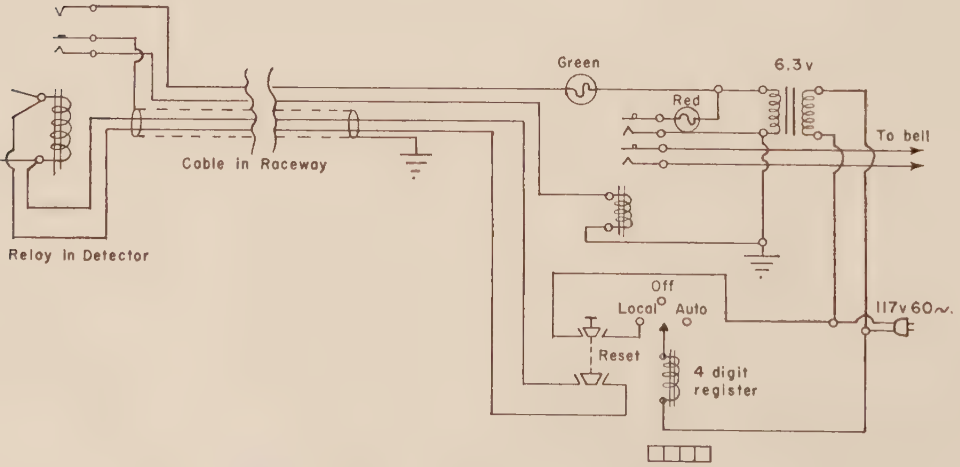


FIG. 8. Schematic of the rack-mounted annunciator.

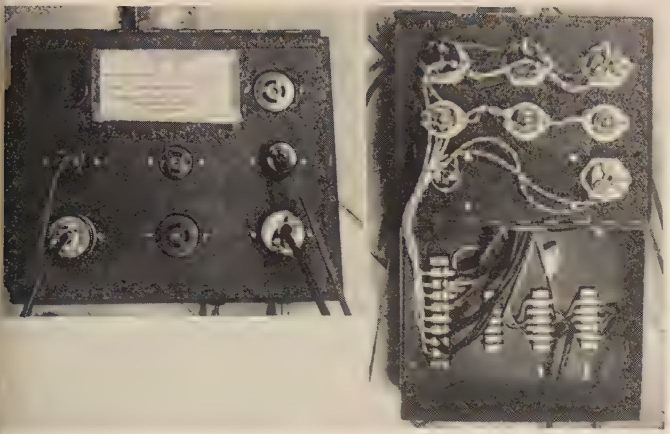


FIG. 9. Outlet boxes.

smaller the 117-volt ac 60-cps power for the amplifier. Five-conductor drop cords for output connection to the central control rack were provided for 2 detectors, with internal connection available for a third cord when desired.

The cable used was Belden 8732, containing one shielded and one unshielded pair. The former pair was used for the relay-coil terminals and the latter for the relay contacts; the shield connection was made to the moveable contact, which is at ground potential.

A separate 117-volt 60-cps convenience outlet was also provided for operating future auxiliary "quiet" electronic equipment and was reserved for this purpose. The main power switch on the central control rack operates this circuit also.

Central Control Rack

The central control rack (Fig. 10) contains, reading from the top: 3 rack-mounted annunciator units; blank panels covering space which is available for 3 additional annunciator units; blank panels covering space assigned to an additional oscillator-and-amplifier combination for a future second frequency; power switches and output meter; and a door which provides access to controls on the oscillator and amplifier for the present bridge supply.

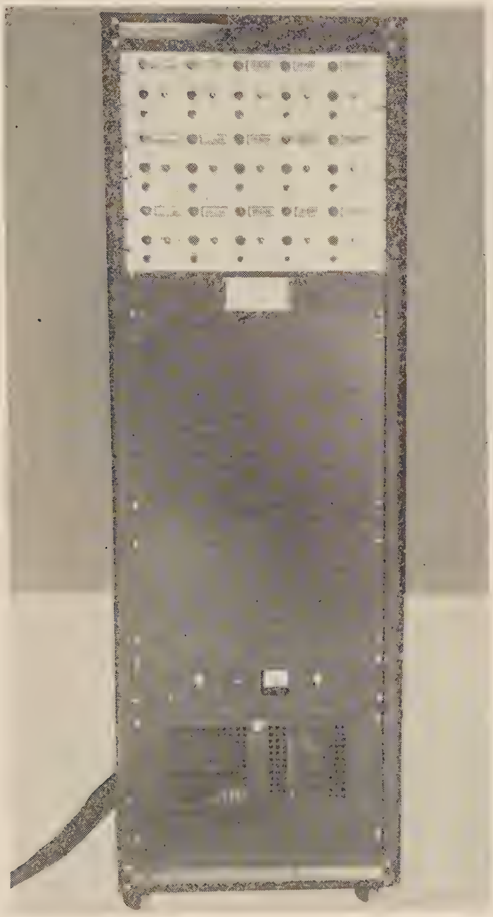


FIG. 10. Central control rack.

A large cable, terminated in 3 A-N type connectors, completes connections to and from the remainder of the system.

A plug-in strip at the left, inside the rear door of the rack, receives power cords from the annunciator units, the oscillator, and its amplifier; the strip is controlled by the main power switch.

Junction Boxes

All connections external to the central control rack are accessible in each of the two junction boxes (Fig. 11). One was mounted on the north wall, and one on the south wall, adjacent to the flow controls. Only the south junction box cover was equipped with A-N connectors to receive the central control rack, due to budgetary considerations. If it later should become necessary to move the central control rack, modification of the north junction box cover is possible.

Summary

To date, the system has been used for detecting fish entering and leaving the facility. The series of experiments for which the equipment was designed is planned for the summer of 1957; the intervening time will give the biologists using the system experience in its operation. The detectors have been operated at numerous demonstrations, using portable tanks and live fish, and have also acquitted themselves well in use in the Bristol Bay area of Alaska during summer 1956.

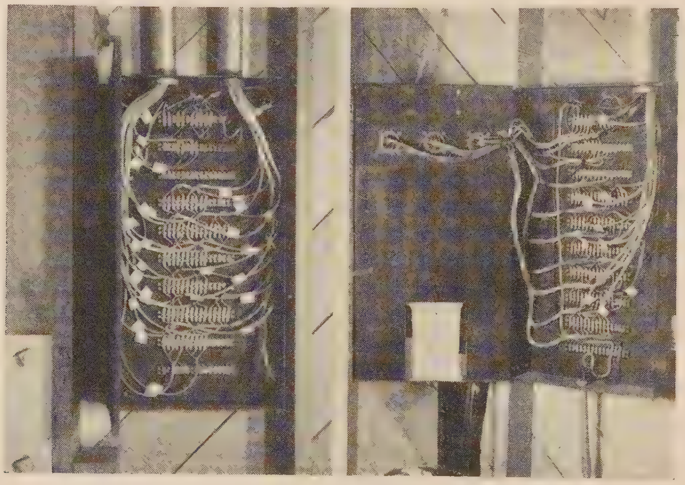


FIG. 11. North and south junction boxes.

JOHN W. VAN LANDINGHAM

A MODIFICATION OF THE KNUDSEN METHOD FOR SALINITY DETERMINATION

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POUR L'EXPLORATION DE LA MER
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A Modification of the Knudsen Method for Salinity Determination

By

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PRIOR to 1955 the conventional Mohr titration for chlorides was in use at the Pacific Oceanic Fishery Investigations laboratory in conjunction with KNUDSEN's methods for sea-water analysis (OXNER, 1946). In general, reproducibility at the end point was within the range of 0·05% to 0·1% when determinations were made by a skilled operator. Although this degree of precision is considered adequate for the needs of this laboratory, there are limitations to the method.

The Mohr method, as applied to sea water, involves reducing titration time by choosing an empirical and transitory end point in place of a stoichiometric one. As a result, the titration is highly sensitive to changes in such elements of the technique as rate of mixing, velocity of titrant addition, etc.

Another related difficulty is the gross size of the silver chloride aggregates formed during a standard Mohr titration. This heavy flock drastically reduces the surface area of the precipitate and entrains considerable quantities of the solution in the interstices, retarding the ionic exchange at the interface between silver chloride and mother liquor, and resulting in considerable end point variability. And because the Mohr end point is not permanent, a time factor, in addition to depth of colour, must be considered when determining it (U. S. Navy Hydrographic Office, 1949). Thus the entire operation falls into the category of an art, and coping with so many variables taxes the abilities of even skilled analysts.

A third factor is the sensitivity of the end point. The colloidal aggregates of silver chloride partially obscure the initial development of indicator colour, and the re-solution of silver chromate precipitated by local excesses of titrant proceeds somewhat slowly (KOLTHOFF and SANDELL, 1949). The over-all effect, then, is a loss of indicator sensitivity.

It was felt that on theoretical grounds most, if not all, of the above-mentioned difficulties would be eliminated by the use of adsorption indicators, such as di-chlorofluorescein, in the presence of a protective colloid, as used by Fajans (cf. Treadwell and Hall, 1948). Adsorption indicators are organic dyes which are adsorbed on the surface of silver-chloride suspensoids on which the adsorbed Cl^- ion has been replaced by the Ag^+ ion. It is believed that such dyes owe their characteristic colour to the frequency at which the chromophoric group resonates in the molecular system (Brewster, 1953) and that a change in potential external to the molecule (such as occurs at a precipitometric end point) modifies the frequency of resonance and imparts a change in colour to the dye.

Adsorption indicators require a protective colloid (such as starch) to inhibit flocculation of particulate silver chloride. This increases the solid-liquid interface enormously, facilitating ionic exchange and resulting in a non-fading end point. The colour change takes place on the surface of every dispersed silver-chloride particle, thus increasing the sensitivity markedly. It must be remembered, however, that the photo-chemical reduction of ionic silver is accelerated by the sensitizing effect of the dyes (Kolthoff and Stenger, 1947).

Apparently there was little or no interest in Fajans's method among early investigators in the field of marine chemistry. Saruhashi (1953) reports a micro-method using uranin (di-chlorofluorescein), which has a mean deviation of $0{\cdot}01\,^0/_{00}$ on a 1·5 ml. sample. More recently, however, Cox (1954) adapted the method to the determination of salinity in sea water. He used sodium salt of fluorescein and starch as a protective colloid and reported a noticeable increase in precision over the Mohr method. Previous investigators have stressed the fact that the colour change must take place near the stoichiometric end point. However, considering the flexibility of the Knudsen technique, I believe that this is an unnecessary limitation. A series of experiments was undertaken with the following dyes: —

1. Fluorescein
2. Di-chlorofluorescein
3. Indigo disulphonate
4. Brilliant yellow
5. Tropeolin 000 (orange 1)
6. Bromophenol blue
7. Nile blue
8. Alizarin red S. (Alizarin mono sodium sulfonate)
9. Phenosafranin (after Berry and Durrant, 1933, quoted by Kolthoff and Stenger, 1947)

Most of the above compounds can be used in the determination of salinity, but all except phenosafranin have undesirable characteristics. The fluorescein dyes and brilliant yellow were rejected because of instability in contact with starch solution over long periods of time. Indigo disulphonate changes from blue to colourless and is not adsorbed on the micelles. Techniques using bromophenol blue (Treadwell and Hall, 1948, quoting Kolthoff) are somewhat involved. Resonance excitation in nile blue takes place too far from the stoichiometric end point. Alizarin red S., when adjusted to the proper pH, gives a distinct colour change close to the stoichiometric end point. It is relatively stable in preserved starch solution, and with care and skill maximum stirring speed can be used throughout the titration. However, the dye is slightly unstable in sea water and approximately 10 minutes' contact with sea water prior to titration results in etiolation of the end point.

Phenosafranin[1] was the best among those considered in stability, sharpness of end point, and degree of contrast between the two colour phases. It is less sensitive to pH changes and more stable in sea water than Alizarin red S. and appears to be in all respects eminently suited to salinity analysis. The indicator solution is prepared in the following manner: —

1. To 700 ml. of distilled water add 1 g. of sodium benzoate, U. S. P. powder.
2. Bring solution to a vigorous boil.
3. Triturate 40 g. of soluble starch to a very thin paste with cold distilled water.
4. Slowly add the cold starch suspension to the boiling benzoate solution.
5. Continue to boil for 2 to 5 minutes after addition of starch solution.
6. Remove from heat and filter while hot through glass wool and cotton.
7. To 50 ml. of cold distilled water add 2·5 g. of phenosafranin[2] dye. Stir thoroughly and then add the suspension slowly to the hot starch solution.
8. Mix well, and when partially cooled make up to 1,000 ml. volume with distilled water. Use 1 ml. per determination.
9. To each sample add a minimum of 10 ml. of chloride-free distilled water, to inhibit foaming.

As a further refinement the end point has been made virtually insensitive to fluctuations in quality of ambient light by the following techniques: —

1. The immediate titration area is flooded as much as possible with fluorescent light.
2. One half of the outer wall surfaces of titration beakers are painted with white enamel.
3. Light from a Bausch and Lomb spherical microscope lamp is beamed horizontally through the unpainted portion of the titration beaker and at a level of approximately 1 inch above the maximum height of liquid. Thus, the upper surface of the solution is bathed completely in diffuse light. (Any *white* light of sufficient intensity and delivered horizontally is satisfactory.)

We have found that the use of such techniques facilitates detection of the end point and markedly decreases the influence of external fluctuations in light quality, in both MOHR's and FAJANS's methods.

Routine determination follows the Knudsen method, with the exception

---

[1] The adsorption behaviour of phenosafranin apparently differs from the classical concept of such indicators wherein adsorption takes place at the equivalence point simultaneously with the change in indicator colour (BREWSTER, 1953). Evidence indicates that phenosafranin is adsorbed in its primary colour phase (pink) as rapidly as silver-chloride micelles are formed. The secondary phase (blue) appears at the equivalence point subsequent to adsorption.

[2] Phenosafranin (3, 6 di-amino-phenyl-phenazine chloride) is a biological stain and photographic anti-fog. It is manufactured by the Analine Division of Allied Chemical & Dye Corporation, N.Y., color index #840, catalogue #NA–685.

Table 1

Comparative performance data, Mohr method *versus* modified Fajans method

	Mohr Method				Modified Fajans method			
	Titration (double millilitres)	Alpha	k	Cl $^{0}/_{00}$	Titration (double millilitres)	Alpha	k	Cl $^{0}/_{00}$
Copenhagen water								
(19·379$^{0}/_{00}$)	19·326	–	–	–	–	–	–	–
–	19·328	–	–	–	–	–	–	–
–	19·321	–	–	–	–	–	–	–
Average	19·325	+0·054	–	–	–	–	–	–
Copenhagen water								
(19·375$^{0}/_{00}$)	–	–	–	–	19·338	–	–	–
–	–	–	–	–	19·339	–	–	–
–	–	–	–	–	19·331	–	–	–
Average	–	–	–	–	19·336	+0·039	–	–
Sea water A	19·301	–	–	–	19·324	–	–	–
–	19·300	–	–	–	19·326	–	–	–
–	19·301	–	–	–	19·321	–	–	–
–	19·302	–	–	–	19·322	–	–	–
–	19·306	–	–	–	19·322	–	–	–
–	19·301	–	–	–	19·322	–	–	–
–	19·306	–	–	–	19·321	–	–	–
–	19·310	–	–	–	19·331	–	–	–
–	19·301	–	–	–	19·326	–	–	–
–	19·305	–	–	–	19·331	–	–	–
Average	19·303	–	+0·06	19·36	19·325	–	+0·04	19·37
Mean deviation	0·0027	–	–	–	0·0032	–	–	–
% deviation	0·014%	–	–	–	0·016%	–	–	–
Sea water B	18·908	–	–	–	18·930	–	–	–
–	18·913	–	–	–	18·929	–	–	–
–	18·912	–	–	–	18·931	–	–	–
–	18·906	–	–	–	18·941	–	–	–
–	18·918	–	–	–	18·929	–	–	–
–	18·905	–	–	–	18·931	–	–	–
–	18·921	–	–	–	18·937	–	–	–
–	18·915	–	–	–	18·929	–	–	–
–	18·907	–	–	–	18·936	–	–	–
–	18·918	–	–	–	18·931	–	–	–
Average	18·912	–	+0·06	18·98	18·932	–	+0·05	18·98
Mean deviation	0·0047	–	–	–	0·0032	–	–	–
% deviation	0·025%	–	–	–	0·017%	–	–	–
Sea water C								
Operator # 1	19·292	–	–	–	–	–	–	–
–	19·291	–	–	–	–	–	–	–
–	19·291	–	–	–	–	–	–	–
Average	19·291	+0·054	+0·06	19·35	–	–	–	–
Mean deviation	0·003	–	–	–	–	–	–	–
% deviation	0·002%	–	–	–	–	–	–	–
Sea water C								
Operator # 2	–	–	–	–	19·361	–	–	–
–	–	–	–	–	19·362	–	–	–
–	–	–	–	–	19·361	–	–	–
Average	–	–	–	–	19·361	—0·002	0·00	19·36
Mean deviation	–	–	–	–	0·0003	–	–	–
% deviation	–	–	–	–	0·002%	–	–	–

of the indicator. However, a few precautions must be considered. From the standpoint of speed and efficiency, particularly in routine determinations, it is desirable to maintain maximum stirring speed throughout the entire titration. In order to accomplish this, the titrant must be introduced at the extreme periphery of the rotating solution at the beaker wall. At this point the linear velocity is low enough to permit local excesses of titrant to accumulate in a thin purple streamer which precedes the final stoichiometric change. However, the onset of the end point is so sudden that, at rapid mixing speeds and maximum titrant delivery, a high degree of visual alertness is required to detect the faint streamer of colour which precedes the stoichiometric colour changes. In stead of such a technique, the solution may be titrated rapidly at a very low stirring speed until local excesses of titrant produce distinct colour changes in the solution. Stirring may then be increased to maximum and after decoloration the titration continued, dropwise at first and then with fractional drops near the end point.

Reference to the performance data (Table 1) shows that precision is comparable between the Mohr and modified Fajans methods, the two agreeing well within the limits of experimental error. The absolute accuracy of the new method as checked against Copenhagen water is certainly as good as, if not better than, the Mohr method. It should be pointed out that the titrations shown in the performance data were done with the improved lighting technique described previously. Thus, the precision indicated is greater than has been encountered in standard Mohr techniques. In spite of this improvement in the Mohr method, long-term experience with thousands of determinations performed by different operators has shown a 25% increase in output for the phenosafranin method. This is primarily due to a marked decrease in the number of faulty titrations and in the number of standardizations required. It has been shown that this method is more easily and quickly mastered by completely inexperienced personnel. Although the samples chosen for comparison in this paper differ in chlorinity by only $0{\cdot}5\,^{0}/_{00}$, practical experience at POFI has indicated that no difficulties were encountered with samples varying in solids content from $32{\cdot}5\,^{0}/_{00}$ (sea water) to $117{\cdot}9\,^{0}/_{00}$ (samples from enclosed lagoon, Laysan Island, Hawaiian archipelago).

A table of the titration characteristics of the two methods is shown below.

Standard Mohr method	Modified Fajans method
1. Empirical non-permanent end point.	1. Stoichiometric permanent end point.
2. Sensitive to rate of mixing.	2. Not sensitive to rate of mixing.
3. Colour intensity continues to increase beyond the end point if titration is continued.	3. Colour intensity remains constant beyond the end point.
4. Alpha values may vary greatly with changes in ambient-light quality.	4. Alpha values remain constant with changes in ambient light.
5. Relatively large flock which is responsible for fading end point.	5. Colloidally dispersed precipitate.

Summary

A new adsorption indicator method for determining salinity of sea water is described. Experience over a period of twelve months has shown this method to be more trouble-free than the standard Mohr method. The number of determinations per man-hour has been increased, and a general increase in precision among all workers has been noted. This has been confirmed by other workers using other organic indicators of the same general type. The table of performance data has been included, not to prove the claim for greater precision, but rather to show that *accuracy* is comparable between the two methods. The author feels that superiority in precision can be proven only by a long-term statistical analysis of routine data.

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FAUNA, FLORA AND THEIR ENVIRONMENT

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FOREWORD

The Great Lakes Commission is pleased to make Dr. John Van Oosten's bibliography on the Great Lakes fauna, flora and their environment available to persons interested in the Great Lakes. Its usefulness will extend not only to students of the hydrobiology of the Great Lakes but also to workers in governmental agencies, industry and elsewhere carrying on investigations in this and other fields.

The Great Lakes and their fauna and flora are unique and important natural resources contributing in numerous ways to the life of the region and the nation. Expanded research on the Great Lakes will build a more solid foundation for wise management and utilization of these resources.

An important purpose of the Great Lakes Commission is to undertake, encourage and assist studies leading to further improvements in the development, use and conservation of the water resources of the Great Lakes. It is hoped this bibliography will stimulate and broaden interest in research on the Great Lakes and will provide encouragement and assistance to those engaged now and in the future in studying these very important waters and their resources.

Marvin Fast
Executive Director
Great Lakes Commission

PREFACE

The growing storehouse of knowledge on every subject under the sun is far more vast than the casual observer would think. Consequently, it becomes ever more difficult to master the information pertinent even to highly specialized fields of human endeavor. Yet for various phases of human activity this must be done over and over again. For efficiency in progress bibliographies are highly essential and of great value.

Picture a scholar about to attack a small problem. After carefully framing the question of his investigation, he needs immediately to know whether or not it has been solved before. If it has not been solved, but has been worked upon, he needs to be aware of the attempts that have been made and the degree of success and the reasons therefor. With such information he is enabled to proceed more efficiently.

The field of hydrobiology is poorly serviced by bibliographies in comparison with many fields of science. Recognizing the need, the international Great Lakes Fishery Commission is sponsoring a project which will assemble references on Great Lakes biology and ecology. However, usefulness of the project--for which the Ontario Fisheries Research Laboratory holds a contract--will be limited because publication in book form is not intended at the present time.

The bibliography by Dr. John Van Oosten will greatly expedite work in many pure and applied aspects of the aquatic biology of the Great Lakes. It also provides a mid-century measure of the progress in the studies of the life of these waters and of the effects of man and other environmental forces on this life--all of which are changing more rapidly than ever before. Dr. Van Oosten has provided students of the area with a master guide through the scattered maze of published accounts on an aspect of the Great Lakes in which there is wide interest. The publication of this bibliography culminates more than forty years of effort by the author in the compilation of the materials. During this period he has headed investigations on the Great Lakes for the U. S. Fish and Wildlife Service and has taught at the University of Michigan.

It is a privilege to express for students, past, present, and future, their gratitude, admiration, and respect for the unselfishness of Dr. Van Oosten in bringing this work to completion.

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INTRODUCTION

International and national interest in the Great Lakes has grown with rapid strides in recent years partly because of the St. Lawrence Seaway and the havoc wrought by the sea lamprey on the fisheries. Three organizations have recently become actively interested or engaged in biological research on the Great Lakes--the University of Michigan Great Lakes Research Institute, organized some years ago, and the recently established Great Lakes Commission and the international Great Lakes Fishery Commission. The U. S. Fish and Wildlife Service, the Province of Ontario and several states have also expanded their Great Lakes program. The tremendously extended biological program has made it desirable to compile a Great Lakes bibliography with special emphasis on the fauna, flora, and limnology. Such a bibliography will greatly facilitate the research of those biological investigators who wish to become familiar with published reports related to their problems. Many of the publications listed herein contain bibliographies on studies that cover areas other than the Great Lakes. By consulting these the scope of references can be expanded.

I have attempted to make the list on fish and limnology as complete as possible, although I am certain that some papers have been overlooked. The bibliography on the other subjects is less complete. Popular articles in newspapers and magazines have not been included except in those instances where original information has been provided. A few general publications and some bibliographies have been added. Administrative reports have not been listed individually for each year.

If only one lake is involved, it is shown in brackets at the end of the citation. Any comments are also placed in these brackets. If transactions, proceedings, or reports cover the year of publication, then only this year is given. Papers published under joint authorship are listed only under the senior author. The following procedure is employed:

Year of publication	Report for year	Volume	Number	Part	Page numbers or total pages	Single lake
1945.	(1944),	2	(3),	Pt. 1	:22-25 or 30 pp.	[Erie]

Abbreviations for words used in the names of journals and periodic publications have been adapted from Karl F. Lagler's book, Freshwater Fishery Biology. 1952. Wm. C. Brown Co.

The publications have been indexed under broad subjects as follows:

I. Fish
   - A. Biology
   - B. Parasites and diseases
   - C. Taxonomy, catalogs, and records
   - D. Culture
   - E. Fisheries

II. Vertebrates other than fishes

III. Invertebrates (including bottom fauna) other than fish parasites and plankton

IV. Plants (non-plankton)

V. Limnology, including plankton, hydrography, and topography

VI. Geology (largely glacial)

I wish to acknowledge with thanks the assistance rendered by members of my staff in the past and by my present secretary, Oweetah Starr. I am also very grateful to Dr. Karl F. Lagler who encouraged me to compile the bibliography and who obtained funds for publication from the Great Lakes Commission through Mr. Marvin Fast. I also appreciate the splendid cooperation of Dr. Albert G. Ballert who has handled the details involved in publishing the manuscript.

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A. Biology

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1932b. [An investigation of the most suitable natural environment for lake trout fingerlings (continued from 1930).] 25th. Ann. Rept. Ont. Dept. Game and Fish. (1931):54-56. [Ont.]

1932c. See fisheries, 1932b.

1933a. [Introduction of salmon in Sandusky Bay.] The Fisherman, 2(7):5. [Erie]

1933b. Mystery of sturgeon '41' solved. The Fisherman, 2(7):12. [Branded at 41 lbs. in Lake St. Clair; recaptured 28 yrs. later in Lake Mich.]

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V. LIMNOLOGY, INCLUDING PLANKTON, HYDROGRAPHY, AND TOPOGRAPHY

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1937. Saginaw Valley report. Mich. Stream Control Comm.: 104 pp. [Chemistry, temperatures, turbidities, pollution of Saginaw Bay.]

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1954b. Great Lakes fishery investigations. Fishery and limnological survey of southern Lake Michigan. Com Fish. Rev., 16(10):25-26. [Mich.]

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OBSERVATIONS ON THE FOOD AND GROWTH OF JUVENILE AMERICAN SHAD, *ALOSA SAPIDISSIMA*[1]

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OBSERVATIONS ON THE FOOD AND GROWTH OF JUVENILE AMERICAN SHAD, *ALOSA SAPIDISSIMA*[1]

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Abstract

Previous studies on the food habits of juvenile American shad have been restricted to one area such as an individual river or a group of ponds. In this study juveniles were obtained from six widely separated rivers. It was found that the food taken, mostly insects and crustaceans, was approximately the same in all rivers sampled. In general young shad appeared to utilize those food organisms which were most available in their habitat at a particular time. Phytoplankton was not observed in any of the 453 stomachs examined. The average lengths of the shad sampled from the various rivers, excluding the Pamunkey River sample, were similar although the southern river samples spawned earlier than those from the more northern rivers.

Introduction

The American shad *(Alosa sapidissima)* is an anadromous fish that spends most of its life in the sea. Each spring the sexually mature adults return to their native stream to spawn. The new year-class spends its first summer and early fall in the river and then returns to the ocean. Details on the life history of shad can be found in the papers of Leim (1924).

During August, 1954, juvenile shad were obtained from several rivers along the Atlantic Coast to determine if there were differences in average growth and types of food taken. A sample of shad was also taken in October at one of the stations. To the author's knowledge no previous coast-wise comparison of this type has been made. Mitchell and staff (1925), examined the stomachs of young shad taken from the Connecticut River and a nearby pond and concluded that insects and crustaceans were the mainstay of the diet. Leim (1924) examined the stomach contents of 40 juvenile shad, 24-25 millimeters in length, taken from the Shubenacadie River in Nova Scotia. Their food consisted mainly of plankton such copepods, amphipods, cladocerans, insect larvae, ostracods, and water mites. Maxfield[2] studied the food habits of juvenile shad reared in ponds in Maryland and found that the major food items were ostracods, insects, insect larvae, copepods, and cladocerans.

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[1] The shad investigation of the U. S. Fish and Wildlife Service, of which this study is a part, is being carried on to furnish information for fishery regulations to the Atlantic States Marine Fisheries Commission.

SAMPLING METHODS

The rivers sampled in this study were the St. Johns in Florida, the Ogeechee in Georgia, the Neuse in North Carolina, the Pamunkey in Virginia, the Hudson in New York and the Connecticut in Connecticut. Samples were obtained with a surface trawl similar to that described by Massmann, Ladd, and McCutcheon (1952) in all the rivers except the Hudson River where a portion of the sample was obtained with a 20-foot beach seine. The trawl sampling was done after sunset because daylight trawling yielded few shad.

Specimens were removed from the net and preserved in 10-percent formalin. The majority of young shad had suffocated before their introduction into formalin and therefore, regurgitation of stomach contents was at a minimum. Samples were taken to the laboratory where specimens were measured (fork length in millimeters) and the stomachs were removed at random from one-half the individuals in each sample. It was assumed that the results obtained through the study of one-half the sample would be representative of the food taken by the entire sample. Samples from each river were kept separate. Stomach contents were examined with a binocular microscope. In all 453 stomachs were examined, each of which contained some type of food.

FOOD OF JUVENILE SHAD

In this study the frequency-of-occurrence method was used to express the type of food present. The percentage of stomachs in each sample containing a given organism is tabulated in Table 1. Frequently copepods, cladocerans, and many of the insects were considerably broken up and often only a portion of the bodies of food animals could be found. This often made complete identification difficult or impossible.

The St. Johns River sample was taken from three locations; Lake Monroe, Georgetown, and Mandarin. The stomachs from this sample which were examined contained little food. The food taken consisted of ostracods, hymenopterans, insect larvae and unidentifiable insects. Marine decapod larvae were found only in the sample taken at Mandarin, which is nearer to salt water than the other locations. Ostracods were noticeably absent from this latter sampling location.

The stomachs obtained from the Ogechee River fish contained little food. The material found in them consisted mainly of unidentifiable insects and animal residue, plus cladocerans and marine decapod larvae.

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[2] Maxfield, G. H. 1952. The food habits of hatchery-produced pond-cultured shad (Alosa sapidissima) reared to a total length of two inches. Masters Thesis, Univ. of Wash.

In the August sample from the Neuse River there was much variation in the type of food taken as well as the amount of food found in the individual stomachs. Crustacean eggs and mayflies made up the bulk of the identifiable material. The Neuse River sample taken in October indicated a much different diet from that found earlier. Stomach contents of fish in the fall sample consisted almost exclusively of insects, excluding Ephemerida. Unidentifiable small fish were also present in some of the stomachs; small cyprinid minnows and anchovies (*Anchova* sp.) 10 to 20 millimeters in length. Mitchell and staff (1925) also reported finding small fish—various minnows, small sunfish (*Lepomis* sp.) in the stomachs of young shad. The occurrence of fish in 24 percent of the October collections from the Neuse River indicates that the ability of juvenile shad

TABLE 1.—*Frequency of occurrence of various food items in stomachs of juvenile shad, expressed as percentage of number of fish examined*

Location	St. Johns River	Lake Monroe	Georgetown	Mandarin	Ogeechee River	Neuse River	August sample	October sample[1]	Pamunkey River	Hudson River	Surface trawl	Beach seine	Connecticut River	Below Enfield Dam	Above Enfield Dam
Type of food															
Decapod larvae	—	—	—	38	17	—	2	13	5	—	—	—	—	—	—
Copepoda	—	12	7	4	—	—	—	7	—	—	28	3	—	57	100
Ostracoda	—	47	93	—	—	—	14	—	22	—	24	—	—	2	7
Cladocera	—	6	—	42	20	—	4	—	—	—	4	—	—	76	84
Crustacean eggs	—	12	7	4	—	—	27	6	3	—	4	13	—	60	42
Ephemerida	—	—	—	—	—	—	25	—	74	—	—	—	—	—	5
Homoptera	—	—	—	—	—	—	2	54	—	—	—	33	—	—	—
Hemiptera	—	—	—	—	5	—	—	4	—	—	—	13	—	—	—
Hymenoptera	—	65	50	13	—	—	8	85	4	—	8	17	—	12	5
Coleoptera	—	—	—	—	6	—	—	17	1	—	—	13	—	—	—
Diptera	—	—	—	—	8	—	4	48	—	—	36	80	—	42	32
Diptera larvae	—	—	—	—	—	—	—	4	1	—	32	77	—	—	—
Diptera pupae	—	—	—	—	—	—	—	4	1	—	—	23	—	14	—
Insect eggs	—	—	—	—	—	—	—	—	59	—	—	—	—	—	—
Unidentifiable insects[2]	—	24	57	38	28	—	20	15	18	—	60	37	—	43	26
Miscellaneous insect larvae	—	35	36	21	11	—	8	—	—	—	—	—	—	67	5
Nematoda	—	—	—	—	6	—	—	—	25	—	8	20	—	21	—
Unidentifiable animal remains	—	—	—	—	22	—	22	—	4	—	—	—	—	—	—
Araneida	—	—	—	—	—	—	2	—	—	—	—	—	—	—	—
Fish	—	6	—	—	—	—	—	24	1	—	—	—	—	—	—
Fish larvae	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—
Number of stomachs examined	—	17	14	24	65	—	51	54	112	—	25	30	—	42	19

[1] This sample was taken at the same location as the August sample.
[2] Partially digested.

to take fish as food may increase with an increase in length. The mean length of the 98 juvenile shad collected in August from the Neuse River was 51 millimeters (range 35-83) while that of the 55 juveniles collected in October from this same river was 75 millimeters (range 62-93).

The stomachs of young shad taken from the Pamunkey River were generally full. The main diet at the time of sampling was Ephemerida and insect eggs. Nematoda and Ostracoda were also well represented in the sample.

The Hudson River trawl sample was taken in a cove where the water averaged about six feet in depth. The stomachs of these shad contained little food while those from the shore-seine sample were full. The sample from the cove contained ostracods, copepods, and insects while insects made up most of the food in the beach area.

The sample from the Connecticut River was taken both above and below Enfield Dam near Thompsonville, Connecticut. The stomachs of the shad taken from the impounded area were full and the food consisted of copepods and cladocerans and a few insects. The sample from below the dam showed a preponderance of insects and insect larvae with few crustaceans.

It is evident from the data that the diet of juvenile shad is diversified. Insects and crustaceans seem to be the main dietary items in rivers but the food differs somewhat in any river and in different rivers. Apparently juvenile shad will utilize those food organisms which are most available in the habitat at a particular time. Phytoplankton was not observed in any of the 453 stomachs examined in this study. This finding is in agreement with Maxfield[2] who stated that the absence of algae in the digestive tracts suggests that young shad seek out zooplankton in preference to phytoplankton as food.

GROWTH OF JUVENILE SHAD

The fork length was determined for all shad in each sample and averages and ranges of these measurements are shown in Table 2. Assuming that

TABLE 2.—*Length of juvenile shad taken from several Atlantic Coast rivers, 1954*

River	Date of collection (August)	Number of fish taken	Fork length (millimeters)	
			Range	Average
St. Johns	9-11	112	39-74	54
Ogeechee	13	130	42-76	55
Neuse	17-18	98	35-83	51
Pamunkey	20-23	223	47-85	65
Hudson	29	110	45-65	54
Connecticut	27-28	217	37-84	54

the sample from each river was representative and a true indication of juvenile-shad growth, comparisons of growth in the different rivers can be made. In the Pamunkey River juvenile shad were of a larger average size (65 millimeters) and in the Neuse River of a smaller average size (51 millimeters) than in the other streams. In the other streams the average lengths of the fish in August were 54 and 55 millimeters. Similarity of average lengths in the different rivers was unexpected because the peak of shad spawning in the St. Johns River is in March, whereas the peak in the Connecticut River occurs in May.[3] On the basis of age alone, an increase in average length from north to south would be expected. Apparently environmental factors may cancel out growth differential which might be expected from differences in spawning dates.

ACKNOWLEDGMENTS

The author wishes to thank Mr. William Massmann, Virginia Fisheries Laboratory, for his aid in obtaining the Pamunkey River sample of juvenile shad. Thanks are also due Mr. Arnold Golding for his aid in the collection of samples, in the examination of stomach contents, and in the tabulation of results.

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[3] Unpublished data U. S. Fish and Wildlife Service, Beaufort, N. C.

U. S. FISH AND WILDLIFE SERVICE

Task Force in the Marquesas

Reprinted from PAN AMERICAN FISHERMAN 11(12): 6-7, 14. July 1957.

Figure 1—Tuna school at stern of M. V. Charles H. Gilbert.

U. S. FISH AND WILDLIFE SERVICE

Task Force in the Marquesas

By ROBERT C. WILSON
and THOMAS S. AUSTIN

THE Pacific Oceanic Fishery Investigations (POFI) of the U.S. Fish and Wildlife Service recently used the "task force" approach in an effort to evaluate the tuna resources of the south central Pacific.

Multiple-vessel cruises were made to the region of the Marquesas Islands to obtain answers to questions concerning the availability of both surface and deep-swimming tunas, their distribution, and their relationship to their environment, the ocean. Although these cruises were primarily of exploratory nature, they produced information which affords definite conclusions of immediate interest.

The Marquesas are the most northeasterly of the islands of French Oceania. They lie about 330 miles farther from Southern California than do the Galapagos Islands (see fig. 2). This fact has, in recent years, stimulated an interest in the possible development of tuna fishing grounds in the Marquesan area by the long-range segment of the tuna clipper fleet. Such an interest is a logical development. In fact, in 1955 the M.V. *Paramount*, a San Diego-based tuna clipper, spent two weeks scouting the Marquesas group; tuna schools were reported as numerous, but the fish did not bite well.

In planning the Marquesan surveys, two periods, the southern hemisphere winter and the southern hemisphere summer, were selected in order to afford the greatest contrast in environmental conditions, and possibly in tuna abundance. A two-vessel task force was formed for the winter survey (August - September, 1956), and a three-vessel force for the survey during the Marquesan summer (January-March, 1957). The specific vessel assignments and the missions of these vessels were:

Winter: *Hugh M. Smith*—Oceanography and productivity

Charles H. Gilbert—Live-bait and longline fishing

Summer: *Hugh M. Smith*—Oceanography and productivity

Charles H. Gilbert—Live-bait fishing

John R. Manning—Longline fishing

Both of these surveys were completed; the survey area is shown in figure 3. The results of these efforts are in part summarized by the following series of questions and answers:

Q. Were there many tuna around the Marquesas, and was there a seasonal variation in their availability?

A. Skipjack were plentiful in the Marquesas during the summer months. More than three times as many schools were seen during the summer cruise as during the winter. A total of three scouting surveys were made, each following the track covering the immediate vicinity of the Marquesas group, as shown in figure 4. Results of these surveys may be summarized as follows:

			Schools sighted		
Time	Total	Skipjack	Yellowfin	Mixed	Unidentified[1]
Mid-Sepember	26	5	—	—	21
Late January	80	40	4	4	32
Late February	89	21	7	—	61

[1] "Unidentified" schools are those where tuna were seen, but not identified as to species.

Mr. Wilson is Fishery Research Biologist, and Mr. Austin is Oceonographer, Pacific Oceanic Fishery Investigations, U.S. Fish and Wildlife Service, Honolulu, T. H.

Figure 2—Distances to the Marquesas Islands.

More Questions and Answers

Q. How did the fish behave?

A. In general, the schools were wild and fast-moving. Most of the dentified schools were skipjack. Typcally, the skipjack schools were coninually changing — segments of schools breaking off from the main ody, rejoining, etc. Virtually all of he fish in schools identified as yelowfin were large, from 50 to 100 ounds in weight, and these schools were also fast-traveling.

Q. Did the tuna bite well?

A. No. During the summer cruise, 99 trials were made with live-bait on una schools. Fish from 36 schools responded to the point where a catch of one or more tuna was made, whereas a catch of 100 or more was made from only 12 schools. The results may be summarized as follows:

School composition	Number of trials	Catch 1 or more tuna	100 or more tuna	250 or more tuna	500 or more tuna
Skipjack	68	29	12	7	3
Yellowfin	18	2	0	0	0
Unidentified	7	0	0	0	0
Mixed, YF-SJ	5	4	0	0	0
Little tunny	1	1	0	0	0

It should be pointed out here that the catches of tuna in the table above cannot be translated into performance by a tuna clipper, because the POFI vessel was at times catching fish at a slow rate for tagging with a reduced number of men in the racks. Also, the need for covering the entire area during the visual scouting surveys did not permit fishing each school fully. Tuna bit at an equally slow rate during the winter cruise.

Q. What was the size of the tuna caught?

A: Of the total catch of 4,838 skipjack during the summer cruise, 90% were 9 pounds or under in weight, with most of the fish weighing about 6 pounds. Of the remaining 10% of larger skipjack, those weighing about 16 pounds occurred most frequently. During the winter cruise the predominant weight was 5 pounds. The yellowfin caught from schools mixed with skipjack weighed 5-6 pounds, while yellowfin from "pure" schools weighed 50-100 pounds.

Q. How many tuna were tagged?

A. We tagged 797 skipjack and 10 yellowfin using the new POFI dart tag.

Q. Is there any bait around the Marquesas?

A. Yes. There is the Marquesan sardine, which is similar in appearance to flatiron herring of Lower

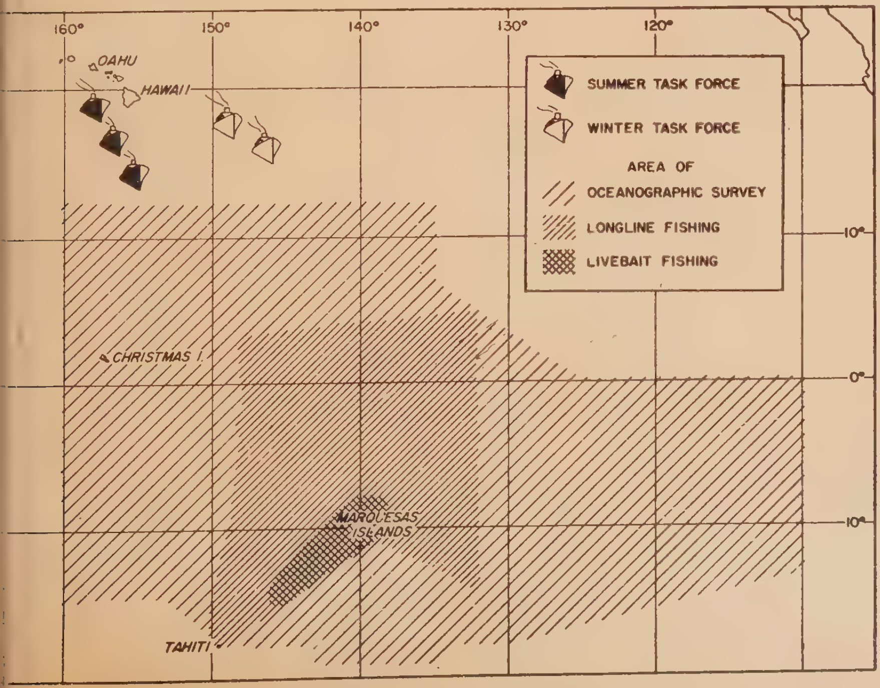

Figure 3—Survey area: POFI 1956-57 cruises to the southeast Pacific.

(Continued on next page)

FAWS TASK FORCE IN THE MARQUESAS

(Continued from previous page)

California, and averages about 3½ inches in length. Also, there is a species of goatfish, slightly larger.

Q. How does the bait behave?

A. The sardines school up and return to the boat when thrown as bait. The goatfish are unsuitable for bait because they scatter and dive.

Q. How much bait was seen?

A: A large supply of sardines was observed in some of the bays. Surveys for bait were made in 16 days of the Marquesas, and varying quantities of sardines were found in 12 of them. Typically, sardines were seen during daylight hours in shallow water over sandy bottom. Six of the most productive baiting localities are listed as follows:

1. Taio Hae Bay, Nuku Hiva I. Most reliable bait source. 1,200 scoops seen, 1-24-57. Good protection from weather and short tow to vessel.

2. Anaho Bay, Nuku Hiva I. 5,000 scoops seen, 1-31-57; 500 buckets caught. Bad surge in NE weather.

3. Taipi Vai, Nuku Hiva I. 100 scoops caught, 2-4-57. No general survey made. Good protection from weather, but long tow to vessel.

4. Haka Ehu, Nuku Hiva I. 130 scoops caught. 3-5-57. No general survey made. Bad surge in NE weather.

5. Taa Huku Bay, Hiva Oa I. 40 scoops caught, 1-27-57. None seen, 2-27-57. Good protection from weather.

6. Hatiheu Bay, Nuku Hiva I. 50 scoops caught, 2-8-57. Bad surge in NE weather.

Sardines of all sizes were attracted to a light at night. It was found that more were attracted to the vessel by the diffused light of a floodlight, than by intense light from a single bulb. Seven sets were made with a night net, and catches ranged from 4 to 130 scoops of sardines per set, with the average catch 44 scoops.

Q. Did the sardines survive well in the tanks?

A. Extremely careful handling was required, or a large percentage would die within 12 hours after being placed in the wells. Once settled, they milled well. When properly cared for, they survived for an extended period in the wells.

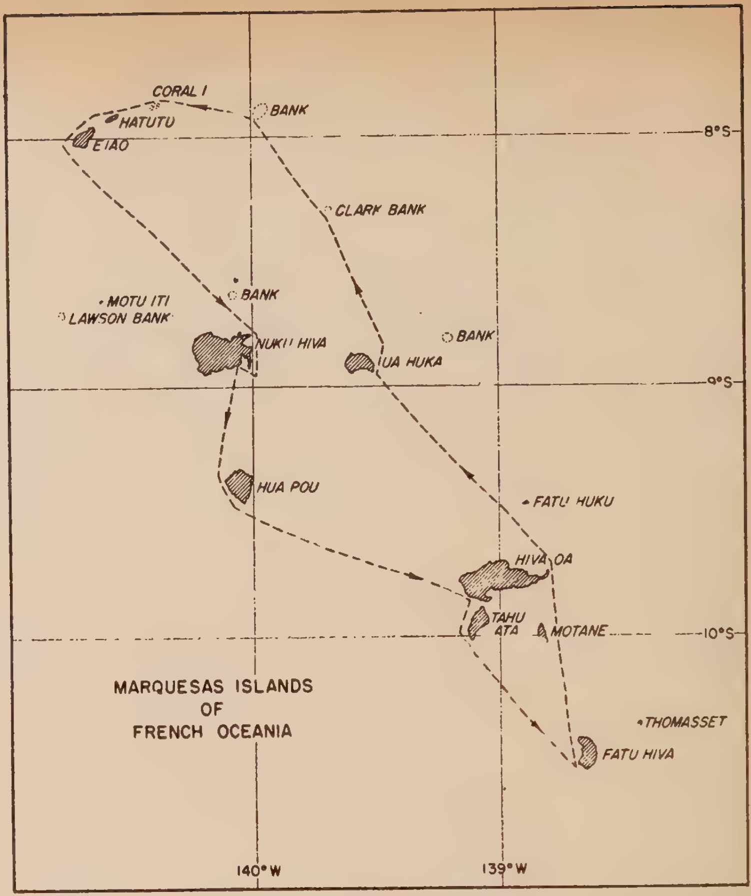

Figure 4—Track of Charles H. Gilbert in scouting for tuna schools for each of three periods including (1) September 7-15, 1956, (2) January 25-30, 1957, and (3) February 23-March 1, 1957.

Q. What did the oceanographic surveys reveal?

A. The currents in the general region of the Marquesas and the Tuamotus were setting onto the islands from the southeast during the winter survey. Those observations which tell us about the potential tuna forage in the area indicated that the waters downstream from the islands were relatively rich. Analysis of the data from the summer survey are not yet completed.

Q. What about the deep-swimming tuna?

A. Some good catches of large yellowfin (7-8 per hundred hooks) were made in the immediate vicinity of the Marquesas during the summer cruise. Longline catches in the rest of the survey area were small, both in summer and winter.

Q. Do you plan additional surveys in the Marquesas?

A: Yes. We plan to return to the Marquesas in order to study in greater detail the extent of the season of greatest availability of surface schools of tuna, and to learn more about their behavior.

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EXPERIMENTAL INDUCTION OF BLUE-SAC DISEASE

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ABSTRACT

Blue-sac disease, an abnormal condition of sac fry, has been recognized for nearly 90 years. At least 23 postulated causes have been advanced, but reports of consistently reproducible results have not been found in literature. Methods whereby blue-sac disease was induced at will are described. Closed-system incubation, whereby metabolic wastes accumulated, resulted in incidences of blue-sac disease roughly proportional to the period of holding and to ammonia concentrations which developed. Blue-sac disease was also induced by adding synthetic nitrogen compounds to water used for incubating eggs and fry.

INTRODUCTION

The following statements, according to Stone (1872) are axiomatic in fish disease research.

> "1. No trout dies without a cause
> 2. The causes of death are discoverable
> 3. They can, in most instances, be removed."

Much progress has been made since Stone wrote his lucid axioms, but there are still many fish diseases about which little is known and for which controls have not as yet been found. Blue-sac disease is one of these. It has been recognized for nearly 90 years, but relatively little has been known of its nature and cause; nothing known about its treatment or prevention.

NATURE OF BLUE SAC DISEASE

Blue-sac disease is an abnormal condition that affects the egg and sac fry stages, typically of trout and salmon, but also of other freshwater fishes whose young emerge with a relatively large yolk sac. Affected individuals have an accumulation of fluid around the yolk sac. The fluid usually appears to have a blue color. Though the volume of fluid is small at first it often develops to the extent that the yolk is completely surrounded. It may also invade the pericardium and lymphatic spaces. Blue-sac fry are generally retarded and lethargic, and their yolks are usually more opaque than those of normal fry. Various degrees of white spotting may also be present. Small or diffuse hemorrhages in the head and body are common in blue-sac fry. The yolk sac blood vessels are frequently flaccid and almost colorless; distal portions often appear to be missing.

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[1] P.O. Kearneysville, West Virginia

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Exophthalmus (popeye) is often present, and in advanced cases there is a paralysis-like condition that is probably the result of turgor. Heart rate and respiration of affected fry are quite generally reduced. Histological examination usually reveals hepatic and renal blockage and severe cardiac pathology (Schereschewsky, 1935; Dieterich, 1938).

The disease often causes the loss of entire lots of trout and salmon fry. Plehn (1924) and Schäperclaus (1954) state that it is one of the most common diseases of sac fry of hatchery-raised salmonids. Hofer, the pioneer of fish pathology, recognized the blue-sac condition as the most serious disease of these young fishes (Hofer, 1896).

The literature of fish pathology contains many accounts in which blue-sac disease is mentioned as a secondary item or associated influence, but only 7 references reporting research on this disease (Fiebiger, 1903; von Betegh, 1912; Guberlet, 1931; Atkinson, 1932; Schereschewsky, 1935; Dieterich, 1938; and Wolf, 1954). At least 23 causes have been postulated for blue-sac disease, but none has been consistently demonstrated.

In general, the cause of a disease must be known before it can be rationally controlled. The purposes of this paper are to present the methods whereby blue-sac disease was repeatedly induced, to indicate the nature of the cause and to resolve the apparent conflicts that exist in literature.

Prelmininary investigations by the writer demonstrated that the blue-sac condition is apparently not an infectious disease but is the result of a factor or factors present in closed-system incubation. When eggs were incubated in vessels to which only air was admitted, blue-sac disease resulted. The incidence was usually greatest among the fry which hatched from eggs which had been held the longest. This indicated possibilities of chemical addition or depletion. Tests made of the water during extended closed-system incubation showed that oxygen values were usually about 9 p.p.m.; carbon dioxide was about 2 to 3 p.p.m.; and pH was about 8. According to Ellis (1948), these values are within the normal range of tolerance for freshwater fishes. Ammonia levels were unusually high; they often exceeded 20 p.p.m. Ammonia is one of the principal metabolic waste products of freshwater teleosts (Prosser, 1950), and it is toxic in relatively small concentrations (Ellis *op. cit.)*. For these reasons the study proceeded along lines which would determine whether this agent caused blue-sac disease.

EXPERIMENTS ON INDUCTION OF BLUE-SAC DISEASE

Three experiments were set up to test the hypothesis that ammonia and related compounds cause blue-sac disease.

EXPERIMENT NO. 1. CLOSED-SYSTEM INCUBATION

Eggs from a single rainbow trout *(Salmo gairdneri)* were used in this experiment. Twenty viable eggs, 8 days old, were placed in each of three 500 milliliter flasks to obtain a replicate series. Each flask contained a half-liter of water which remained unchanged throughout the experiment except for samples which were withdrawn for chemical analysis. The flasks were aerated continuously but were otherwise closed systems. At intervals of 4 days three additonal closed-system series were initiated thus, in all, 4 such series of closed-system incubation flasks were started before the eggs began to hatch.

If metabolic wastes are the cause of blue-sac disease, their effect should be minimized or inhibited by removal of them as soon as they were released into the water. Flasks of another closed-system series were therefore fitted with venturi pumps which circulated the water over a bed of activated charcoal; this effected circulation, purification and aeration. Eight-day-old eggs were also used for this series.

Two series of controls were used. In one series eggs were placed in floating plastic baskets which were kept in the trough along with the source lot of eggs. In a second series of controls eggs were placed in aerated flasks to which water was admitted at a rate which gave a change of water every 2½ minutes. Temperature of the water in which all eggs were incubated was 13°C. For ammonia analysis a 5 milliliter water sample was removed every other day from each flask and from the trough containing the baskets. Five milliliters of fresh water were then added to the flasks to maintain a constant volume. Ammonia determinations were made by nesslerization according to the method of Symons (1947), and ammonia determinations are expressed as parts per million of ammonia nitrogen.

A single pipette was used to draw the water samples for chemical analysis. The pipette was not disinfected between the different series, and the order of selection was changed each time. This systematic violation of principles of sanitation was intended to show that infection was not involved in blue-sac disease.

Blue-sac disease was diagnosed by examining each fry every day. Fry were deemed to have blue-sac disease when the volume of their yolk sac fluid equalled that of a preserved standard specimen. The stan-

TABLE 1.—*Average percentage hatch, mortality and blue-sac disease among portions of one lot of eggs incubated under different conditions.*

Treatment	Average percentage hatch	Final percentage mortality	Average peak percentage of fry with blue-sac disease
Lot control (in baskets) at H-17[1]	91.6	13.3	31.0
Experimental control (air and water) at H-17	95.0	28.3	45.2
Closed system w/charcoal at H-17	93.3	100	42.7
Closed system at H-17	none	100	no hatch
Closed system at H-13	86.6	100	90.4
Closed system at H-9	25.0	100	96.6
Closed system at H-5	61.7	100	66.1

[1] H indicates date of hatching; the number which follows indicates the number of days prior to hatching that the series was started.

dard specimen was comparable to Stage I of Dieterich *(op. cit.)*.

Blue-sac disease was induced in a greater percentage of the fry in the closed-system flasks than in the fry in the controls and in the charcoal filter series (Fig. 1 and Table 1). Eggs which had been held the longest in the closed-system flasks died before hatching. There was a hatch of over 90 percent of the eggs in the charcoal filter series which had been started at the same time. Before mortality terminated one series (closed-system H-9), the curves of blue-sac disease of fry in the closed-system series showed a graded incidence; the highest percentage of fish with the disease occurred among the fry of the oldest series, and the lowest percentage in the fry of the youngest series. The highest incidence of blue-sac disease also occurred among the fry of those flasks which had greatest concentrations of ammonia (Fig. 2). Relatively high percentages of blue-sac disease occurred among the fry of both series of controls and in the charcoal series fry, but the percentages were much lower than those for the fry in the closed-system series which was in operation for the shortest time. This is emphasized, because the youngest closed-system series was started only 5 days before hatching and consequently had 12 fewer days for exposure to and accumulation of metabolic wastes.

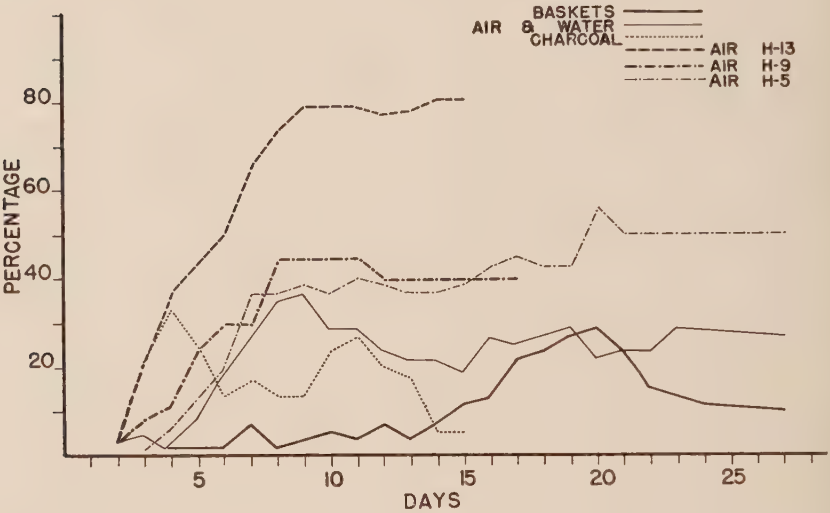

FIGURE 1.—Average daily incidence of blue-sac disease among fry incubated in closed system series (Air; H-13, H-9, H-5) as compared to the incidence among fry in control series (baskets, air and water) and in a closed-system series containing activated charcoal.

The peak occurrence of blue-sac disease in the charcoal series occurred immediately after hatching. Ammonia concentrations rose abruptly during hatching, and in spite of almost daily change of the charcoal, the concentration approached 1 p.p.m. and was slow to be reduced. Some blue-sac disease could have resulted from this exposure to a low level of ammonia.

Previous experiments showed that some blue-sac disease usually occurred in the control fry. In Experiment No. 1 the percentage of diseased fish in the controls, as shown in Table 1, was higher than usual. The difference between the average percentage of blue-sac fry of the two series of controls is difficult to explain. The water manifold which supplied the experimental control flasks was the site of accumulations of gases which escaped from solution. These accumulations temporarily blocked the flow of water especially at night when the flasks went unchecked for hours. Interrupted flow may therefore account for the higher incidence in the control flasks than in the basket controls. In the light of results obtained from Experiment No. 3 it is considered likely that water movement past the eggs in

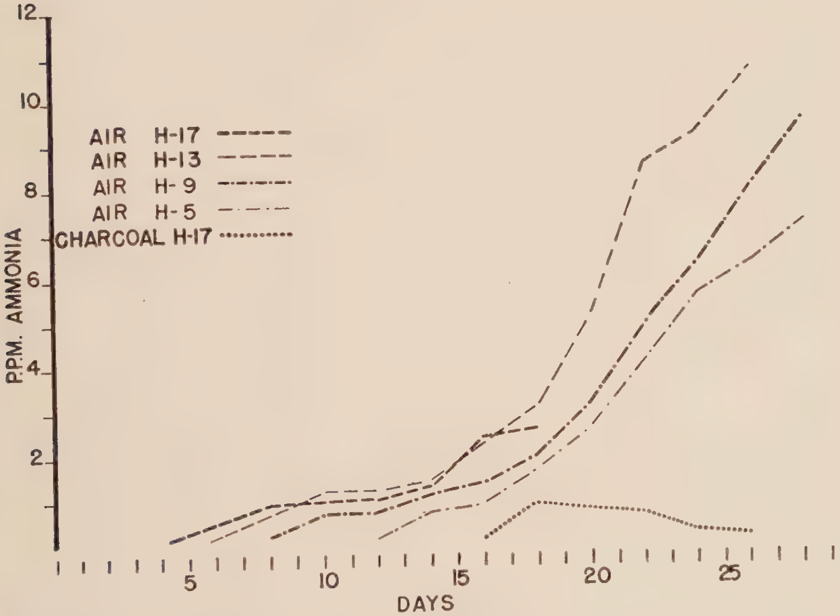

FIGURE 2.—Daily ammonia levels of water from closed-system vessels used in experimental induction of blue-sac disease. Ammonia is expressed as p.p.m. nitrogen. H indicates the date of hatching; the number which follows indicates the number of days prior to hatching that the series was started. Only trace quantities of ammonia were found in the water from both series of controls, therefore, the curves for these series have been omitted.

both the baskets and in the control flasks was not always adequate and that a partial or temporary stagnation occurred.

In spite of regular cross-transfer of water between the series, blue-sac disease showed no evidence of being infectious or of spreading. Oxygen determinations were made on several closed system flasks at termination of the experiment. The values ranged from 6.8 to 8.6 p.p.m. Values for pH ranged from 7.8 to 8.2.

EXPERIMENT NO. 2. ADDITION OF AMMONIUM HYDROXIDE TO INCUBATION WATER

If an accumulation of nitrogenous metabolic wastes caused blue-sac disease, it should be possible to induce the disease by adding synthetic forms of these compounds to water used for incubation. Levels of ammonia reported to be toxic had been found in the preliminary work, and further evidence of the harmful nature of this compound was obtained from Experiment No. 1. Ammonium hydroxide was chosen as the synthetic nitrogen compound for this experiment.

Twenty eggs of brook trout *(Salvelinus fontinalis)* hatchery stock were placed in each of two 500 milliliter Erlenmeyer flasks 9 days before they were due to hatch. Water at about 13°C. was supplied from reservoirs to each flask at a rate of about 1 liter per hour. One flask, the control, received hatchery water. Ammonium hydroxide was added to water supplying the other flask. A concentration of 1.5 p.p.m. ammonium hydroxide was used until the day of hatching. On the following day the concentration was increased to 2 p.p.m. and this level maintained for 3 days. Concentration was then increased gradually and on the 18th day after initiation of the experiment a concentration of 6 p.p.m. ammonium hydroxide was used. This concentration was maintained until termination of the experiment on the 30th day.

Fry in the control flasks and in the flasks which received water to which ammonium hydroxide had been added both developed a maximum incidence of 85-percent blue-sac disease. Average incidence during the last 10 days of the trial was the same for fry of both the experimental and control series. High mortalities in both series forced termination of the experiment, but at that time the disease incidence in the control lot was declining more rapidly than the lot receiving water with added ammonium hydroxide. A 5-percent sample of eggs from the same female trout, which eggs had been hatched in another trough under normal hatchery practice, showed about 9-percent blue-sac disease. Blue-sac disease was induced under the conditions of the experiment, but the effect of addition of ammonium hydroxide was not demonstrated. Partial stagnation may have occurred which could have permitted ammonia in the control flasks to increase beyond the concentration that was added, and thus both groups subjected to conditions favorable for development of a high level of blue-sac disease. The concentration which had been added to the experimental flasks was considerably below the level that accumulated during closed system incubation with a similar number of eggs.

EXPERIMENT NO. 3. ADDITION OF AMMONIUM HYDROXIDE AND UREA TO INCUBATION WATER

This experiment was a modification of Experiment No. 2. Eyed brook trout eggs from several redds were pooled, and 30 eggs were placed in each vessel. Two 200 milliliter straight-walled glass vessels were used instead of flasks. The possibility of hydraulic isolation was eliminated by keeping the eggs in plastic-screen baskets which were snugly fitted a few centimeters above the bottom of the glass vessel. A similar basket capped the glass vessel and permitted overflow without the loss of fry. Siphons of 1 millimeter intake and outlet diameter carried about 100 milliliters of water per minute from elevated reservoirs to each of the 2 glass vessels.

Ammonium hydroxide and urea were added to one reservoir each time it was filled. On the first day ammonium hydroxide and urea were added at both times the reservoir was filled to obtain a concentration of 2 p.p.m. for both substances. The concentration was increased to 4 p.p.m. on the 2nd day, to 8 p.p.m. on the 3rd day and to 10 p.p.m. on the 4th, 5th and 6th days. On the 7th day, a concentration of 12 p.p.m. was used, and this concentration was maintained until termination on the 23rd day.

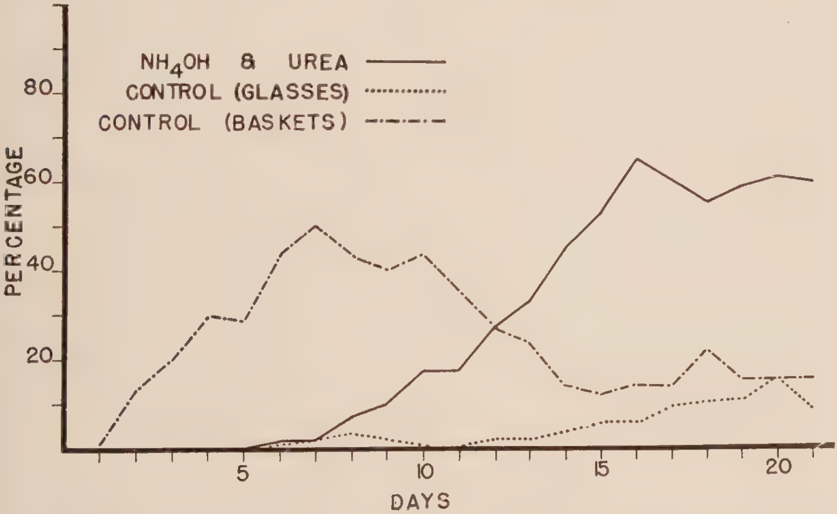

FIGURE 3.—Daily incidence of blue-sac disease among fry incubated in water to which ammonium compounds were added as compared to the disease incidence among fry incubated in water to which ammonium compounds were not added.

Two sets of controls were employed. The first consisted of 2 glass vessels which received hatchery water. The second consisted of 2 plastic-mesh baskets floated in the reservoir which supplied water to the control vessels. Water temperature was about 13°C. throughout the experiment.

An average of 65-percent blue-sac disease developed among fry in the series which had been treated with ammonium hydroxide and urea. Fry of the control vessels which had been treated the same except for the addition of the chemicals had an average of only 15-percent blue-sac disease (Fig. 3 and Table 2), but fry in the series of baskets floating on the surface of the reservoir that supplied the control vessels had an incidence of 50-percent blue-sac disease. This is regarded as almost conclusive evidence against an infectious nature for blue-sac disease. Hydraulic isolation or stagnation appeared to be the explanation. This was verified by dropping crystals of malachite green into the reservoir. The resulting cloud of dye remained nearly intact for hours. Stratification appeared to be present, because streams of dye were seen to move to the siphon intakes along the bottom. If stagnation under such a situation occurs, it was likely to be disrupted when the fry hatch. Their movements would agitate the water, and this would probably alleviate the situation. This supposition was supported by the fact that although the incidence of blue-sac disease was high, the mortality was relatively low. Stagnation probably existed for only a short time before being alleviated by the fry. Further evidence was found in the fact that fry in the control baskets reached their peak incidence of blue-sac disease in 7 days, but the disease incidence among fry in the ammonium hydroxide and urea series continued to increase for 11 days and then declined only slowly (Fig. 3).

TABLE 2.—*Experimental induction of blue-sac disease in fry by the addition of ammonium hydroxide and urea to the incubation water.*

Treatment	Percentage hatched	Percentage mortality	Maximum percentage blue-sac disease
NH_4OH and urea	100	93.4	63.4
NH_4OH and urea	100	80.0	66.6
Control (glasses)	100	3.4	13.3
Control (glasses)	100	6.7	16.6
Control (baskets)	100	0.0	46.6
Control (baskets)	83.4	30.0	53.4

The percentage of hatch was uniformly high in the experimental series and in the controls. There was little spread between the results from each pair (Table 2).

An average total mortality of 86.7 percent occurred among fry of the series which had been treated with ammonium hydroxide and urea. Fry in the series which had been held in floating baskets had an average total mortality of 15 percent.

AN EXPLANATION OF HATCHERY OCCURENCES OF BLUE-SAC DISEASE

The apparent cause of blue-sac disease under experimental conditions remains to be demonstrated as the cause of the disease in the hatchery and in the wild, but there is reason to believe that the cause is the same.

Experimental evidence indicates that blue-sac disease occurs as as result of some form of stagnation, partial, temporary or local, which allows metabolic wastes to accumulate. The accumulation is probably restricted in time and/or space, because more severe conditions would undoubtedly result in death.

The efficiency of water flow used for fish culture has, until recently, been given little more than sporadic, informal, philosophical treatment. Burrows and Chenoweth (1955) recently made a study of the hydraulic characteristics of fish-rearing ponds. They found dead areas present in 3 common types of ponds studied. This writer considers it likely that similar areas of poor or inadequate water flow occur in hatching facilities.

Small-mesh screen used on trays in the Clark-Williams method of incubation often collect huge flat air bubbles between the trays. Overcrowding of eggs and fry was occasionally encountered in all methods of incubation. Mats of debris and/or fungus occasionally blanket some eggs. Water tends to go around such impediments, and this can give rise to localized or temporary stagnation.

Partial or localized stagnation may be the reason why an outbreak of blue-sac disease seldom involves the total lot of fry and why it can occur in trays at the head of the trough without involving lower containers. The common occurrence of severe blue-sac disease in fry from eggs which had been in transit for long periods of time may be a result of the same basic cause. Eggs in transit continue to develop, and waste products are excreted. If such eggs are poorly iced or too densely packed, the volume of melt-water that passes them may not be adequate to remove metabolic wastes. Consequently, even though they are moist, they may be literally surrounded by a film of their own pollution.

Ammonia is probably involved, but other nitrogenous products are not excluded as possibly contributing their influence. If circumstances permit, it is planned for the future to determine quantitative values of time and concentration for ammonia and other products of metabolism excreted by the developing eggs and fry.

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Cultivation of Adult Teleost Tissues *in vitro.* (23250)

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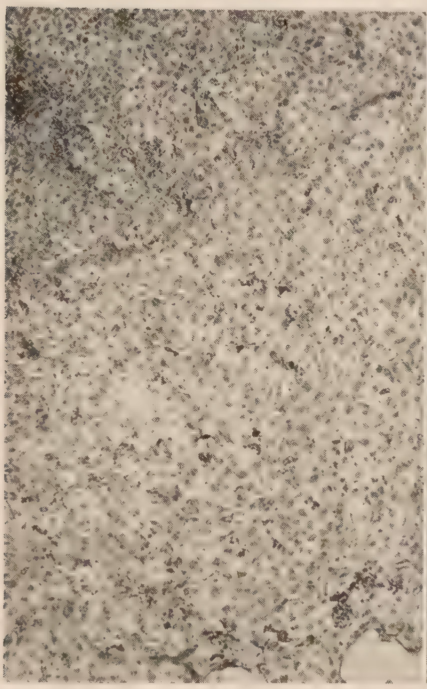
Cultures of normal and abnormal tissue cells from warm-blooded vertebrates are routinely prepared in many laboratories, and there is abundant literature on the subject. In contrast, there is comparatively little information on culture or tissues from cold-blooded vertebrates. Osowski(1) observed cellular movement in fragments of tadpoles and trout which he maintained for as long as 24 hours in Ringer's solution. Sea water and fish bouillon were used as culture medium in other work with fish tissue, but the cultures were short-lived(2,3). Chlopin(4) cultured tissues from pike and crucian carp in rabbit plasma "diluted with homogeneous extract." Lewis and MacNeal(5) cultured pituitary glands from flounder, sculpin and angler fish. Their cultures were "prepared in autoplasma or homoplasma" to which chicken plasma was added. Recently, abnormal tissues of killifish (6) and goldfish(7) were investigated, and in these studies embryonic extracts were added to media composed of chicken, human cord or fish sera and salt solutions. Soret and Sanders(8) propagated the virus of eastern equine encephalomyelitis in fish embryos. There is no information on the culture of tissue cells from salmonids which require low environmental temperatures (10-15°C is the optimum range). Because the culture of host tissues would seem to offer promise as an effective tool in the study of those diseases of salmonids, suspected of being caused by a virus, the initial problem in this investigation was to develop simple and efficient methods of culturing tissues from normal fish. This communication describes the attempts that were made to cultivate salmonid and other fish tissues in certain commercial media.

Materials and methods. Tissues from hatchery-raised rainbow trout (*Salmo gairdneri*) were used for most of the work, but tissues of eastern brook trout (*Salvelinus fontinalis*), brown trout (*Salmo trutta*), and goldfish (*Carassius auratus*) were also cultured. Age of donors ranged from embryonic to adult, but cultivation of tissues from subadult and sexually-mature specimens was emphasized, because embryonic salmonid tissue is usually available only part of the year. Fish were killed just before use by severing the vertebral column immediately back of the head. Care was taken not to penetrate the body cavity. When gill tissue was needed, the arches were excised and washed in a stream of sterile salt solution from a syringe, which probably helped to remove surface bacteria. When sterile internal organ tissue was needed, the fish was immersed for 1 min. in a 1:1000 solution of benzalkonium chloride (Roccal). After draining, excess disinfectant was removed with cotton swabs saturated with 70% ethanol. Instruments were sterilized in boiling water followed by immersion in 70% ethanol and flaming immediately before use. Tissues or organs were removed aseptically, immediately submerged in cold Earle's solution, and maintained at about 5°C until minced with scalpels and placed in culture vessels. Mincing and all subsequent operations were performed in a hood. Throughout the manipulations the tissues and vessels were kept cool on or near trays of ice, partly because growth of trout tissue was not obtained at 26°C and above and partly because failure in early attempts to obtain growth was attributed to high temperatures within the hood during explantation. Because ozone and ultraviolet light also seemed to be deleterious, the hood was thoroughly flushed with fresh sterile air before use. Some tissues were cultivated directly on glass, but better results were obtained when tissues were embedded in a chicken plasma clot. Cultures were made in straight-necked 5 cm Carrel flasks or stationary 16 x 150 mm tubes, either with or without coverslips. Several 2-3 mm^2 x 1 mm explants were used in each culture vessel, with 1.5-2 ml of fluid media in flasks, 1-1.5 ml in tubes. When cultures were to be kept a week or longer, medium was changed in whole or in part every 4-7 days. Viability could often be maintained with weekly renewals. Media used in this work always contained embryo extracts, generally at a level of about 5%. The media also contained from 10-20% serum, and the balance was medium 199 and salt solution with phenol red at 0.001%. Media for internal tissues contained 250-1000 units potassium penicillin G/ml, but penicillin alone did not inhibit contaminants in cultures of gill or fin tissue. Contamination in cultures of external tissues was controlled with 1000 units of penicillin plus 1000 mcg of dihydrostreptomycin sulphate/ml. Best results were usually obtained when the initial pH was adjusted with 5% CO_2 in air to 7.2-7.4, but growth was also obtained at pH 6.8-7.0. Temperature of incubation was 19°C. This investigation did not involve serial transplantation, but some cultures of trout tissue were kept growing for a month and longer, and one culture of goldfish tissue was kept alive for about 10 months.

Results. In general, trout tissues were readily cultivated, but comparable goldfish tissues grew more vigorously. It was necessary to keep trout tissues cool during removal, manipulation and incubation. Swim bladder from eastern brook trout grew well at 12° and 19°C, but more abundant growth was obtained at the latter temperature. No growth of trout tissue occurred at 26° and 37°C. (Maximum temperature tolerance for trout is generally below 26°C.)

Synthetic medium 199 (SM 199) (Difco) and salt solutions were compared for their ability to maintain normal morphology in rainbow trout blood cells. Ringer's frog saline and Holtfreter's solution(9) proved to be unsatisfactory and appeared to be hypotonic. Earle's, Tyrode's, and Hanks' salt solutions and SM 199 gave satisfactory results. Earle's salt solution and SM 199 were judged to be best, and a mixture of the two was used in media for most subsequent fish tissue culture. Growth of trout tissue was obtained in media containing serum, embryo extract and either SM 199, Tyrode's or Earle's, but the results with Tyrode's were inferior. Growth was obtained with chick embryo extract (Difco, desiccated), but a saline extract of newly-hatched trout gave similar results in cultures of trout kidney and minced trout embryos. Beef embryo extract (Difco, desiccated) also supported growth of fish tissues. Either chicken serum or heparinized trout plasma was employed in much of the work, and serum from carp (*Cyprinus carpio*) supported trout kidney tissue. Many sera supported growth of trout swim bladder tissue, but results with horse serum were poor. Sheep and beef sera were slightly better. Chicken and rabbit sera gave fair results, and human serum was as good as homologous serum. Cellular quality and quantity were excellent in human cord serum; bovine amniotic fluid gave healthier cells, but multiplication was slower than in cord serum.

Tissues from kidney, spleen, peritoneum, gills, testes, ovary, fins, and swim bladder of trout were readily cultured. Heart and liver tissues of trout were less easily cultured. Tissue from a common idiopathic granuloma of eastern brook trout(10) yielded a few abnormal fibroblasts. Heart and kidney of goldfish were easily cultured; one heart culture was kept beating for 299 days in 20% chicken serum, 5% embryo extract, 30% SM 199, and 45% Earle's solution. It died when trout serum was substituted for chicken serum in the medium. Swim bladder explants usually exhibited smooth muscle movement for at least several days; one culture, for over 7 weeks. Ciliary movement was usually observed in explants of swim bladder, kidney and spleen. It was often maintained for several weeks, and for 58 days in one culture of trout swim bladder. Other workers(5) have made similar observations of cilia in fish tissues. Occasional individual cells and aggregations of cells which bore cilia separated from the explant and became motile. This phenomenon has been observed in frog epithelium by Duryee and Doherty(11). With the exception of fin epithelium, cells from tissues in a plasma clot usually adhered better and maintained a healthy appearance longer than those from the same tissue cultured directly on glass. Actively proliferating cultures usually produced only a slight drop in the pH of the medium.



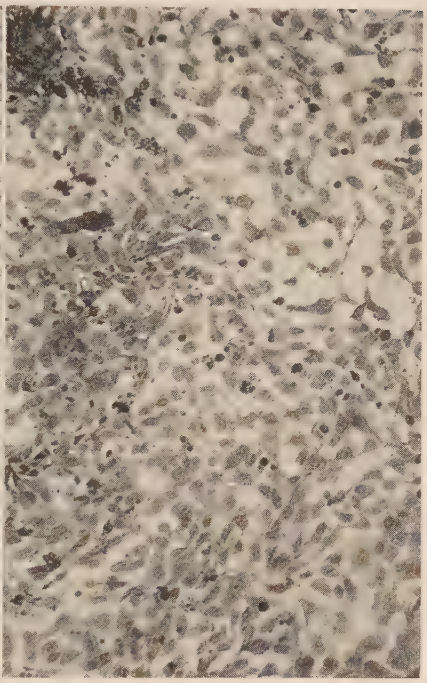


FIG. 1 (left). Cell sheet from 48 hr cultivation on glass of rainbow trout fin. H. & E. × 57.
FIG. 2 (right). Cells from rainbow trout fin in clot after 48 hr incubation. H. & E. × 140.

Gill, swim bladder, kidney and fin tissues from trout regularly gave good cultures. Migration of macrophages was usually evident within hours after explantation and often became extensive. Migration was usually followed by a sheet-like growth of epithelium-like cells (Fig. 1). These sheets grew between the clot and the glass, and at times over the surface of the clot. Sheet-like growth of epithelium was often the first activity of fin, gill and swim bladder tissues. Cells comprising these sheets were polygonal to smoothly contoured in outline (Fig. 2). Their early appearance was hyaline, but with age and especially with media containing chicken serum they became granular and vacuolated. Sheets of older cells often tore or developed holes, which were rapidly covered by a sheet of new cells, and several such cycles were observed in a single culture. Hyaline spindle-shaped cells or cells with multiple processes were the last to appear. This cell type usually overwhelmed earlier appearing cells.

Summary. Normal tissues from trout—a coldwater teleost—have been successfully cultured for as long as 65 days at 19°C or lower in 20% serum, 30% SM 199, 45% Earle's solution and 5% embryo extract. Excellent results were obtained with human cord, human, homologous sera or bovine amniotic fluid when used at 20% level by volume. Manipulation and incubation temperatures below 22°C are thought to be essential.

Appreciation is expressed to Dr. S. F. Snieszko, U. S. Fish and Wildlife Service, for his kind interest, and to Dr. Karl Habel, National Institute of Allergy and Infectious Diseases, for instruction in methods of tissue culture.

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A57. *Strain differences in a fish-pathogenic Corynebacterium.* Ken Wolf and C. E. Dunbar, U. S. Fish and Wildlife Service, Kearneysville, W. Va.

Hatchery-raised salmon and trout are subject to systemic infections with a bacterium that Ordal and Earp consider to be a *Corynebacterium.* The infection, called *kidney disease,* often results in large losses of fish. The authors compared several methods of experimental transmission to susceptible trout, and used two different strains of bacteria. Bacteria were added to food and fed twice-daily to two replicate groups of fish; other replicates were given bacteria and bile salts, and a third group received bacteria and splintered glass. Other fish were held in troughs which contained rough masonry; this forced self-abrasion, and bacteria were added to these troughs 6 times per week. Still other replicates were periodically manually scarified with bacteria-laden abrasive paper. The period of treatment was 101 days. There were no kidney disease mortalities among controls nor among any lot in which the western strain was used. No method of feeding eastern strain bacteria produced kidney disease, but kidney disease with the eastern strain was transmitted by both types of abrasion. Manual abrasion produced the first disease mortality in 48 days and the last fish in this group died of kidney disease at 101 days. Under self-abrasion 96 days elapsed before the fish mortality occurred, and mortalities were still occurring 48 days after termination on the 101st day.

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